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STATISTICAL METHODS APPLIED TO THE STUDY OF RESPIRABLE DUST CONCENTRATIONS IN URANIUM MINES IN CANADA.

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ABSTRACT

Statistical analysis of gravimetric dust sampling observations of respirable quartz and respirable dust, and the statistical evaluation of konimeter observations in uranium mines is an aid for determining worker exposure.

This report describes the techniques used to calculate the mean, standard deviation and the coefficient of variation of both the raw data and the logarithms of the individual observations.

Log-normal theory is used to calculate the best estimate of the means and standard deviations of grouped data.

The results of a computer program are presented to demonstrate the log-normality of respirable quartz, respirable dust and konimeter observations obtained during the period 1974-1980 in Ontario uranium mines.

Finally, the confidence limits for the means of data obtained for nine uranium mine occupations are calculated to graphically demonstrate the relative exposures to respirable quartz and respirable dust.

RESUME

L'analyse statistique des observations de quartz respirable et de poussière respirable par échantillonnage gravimétrique et l'évaluation statistique des observations au conimètre dans des mines d'uranium contribuent à calculer l'exposition des travailleurs.

L'auteur décrit les techniques utilisées pour calculer la moyenne, l'écart type et le coefficient de variation des données brutes et des logarithmes des observations individuelles.

Il utilise la loi de distribution log-normale (loi de l'essai proportionnel) pour calculer les moyennes et les écarts types de donnees groupees.

L'auteur présente ensuite les résultats d'un programme d'ordinateur, qui démontrent que que les observations de quartz et de poussière respirables et les observations au conimètre obtenues entre 1974 et 1980 dans les mines d'uranium de l'Ontario obéissent à une loi de distribution log-normale.

En dernier lieu, l'auteur calcule les limites de confiance des moyennes de données obtenues pour neuf occupations de mines d'uranium et llustre, au moyen de graphiques, les expositions relatives au quartz respirable et à la poussière respirable.

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INTRODUCTION

Exposure to respirable quartz has long been recognized as an occupational hazard. The diseases resulting from these exposures are of the pneumoconiosis type, of which silicosis is one example. These diseases appear in the lung and, generally, are chronic or slowly developing. In Canada, silicosis was observed in the early years of underground mining among metal and non-metal miners, generally where poor ventilation conditions existed or where dust suppression techniques were absent. As health authorities became aware of the relation between silicosis and the airborne hazards which may have contributed to its occurrence, those agencies with authority over mining took steps to have the mining companies introduce forced ventilation and dust suppression techniques to reduce the concentrations of airborne hazards including respirable quartz.

This study forms part of the dust and radon projects at the Atomic Energy Control Board (AECB) and a continuation of the work presented at the "Occupational Radiation Exposure in Nuclear Fuel Cycle Facilities" Symposium (1), and the "International Symposium on Aerosols in the Mining and industrial Work Environment" (2) and INFO Report 0038 prepared for the Atomic Energy Control Board (3) during 1981.

Respirable quartz, respirable dust and konimeter sampling has been carried out in uranium mines in Ontario during the period 1974 to 1980 to assess workers' exposure, efficiency of dust controls and the need for further engineering dust control methods. Before 1974, only konimetry data existed.

Since the most important potential dust hazard in many mines is the concentration of airborne free silica present the variability in biological response to quartz concentrations can only be estimated by epidemiological studies after an accurate record of quartz concentrations has been obtained.

The data were obtained from the results of personal dust sampling using the Canadian Mining Personal Dust Sampler (CAMPED) developed by the Elliot Lake Laboratory of CANMET. (4) (5) (6)

The observations studied were obtained in two Ontario uranium mines as follows:-

MINE A

Series	Sampling Period
1	1977-1978
2	1975-1976
3	1974

MINE B

Series	Sampling Period
4	1980

The statistical analysis is designed to establish baseline data for a Code of Practice document using probability theory.

For employing the curve-fitting techniques shown in the text, the population is considered to be the workers who were wearing the full shift samplers for the period stipulated for each series of data.

Applied Statistical Analysis of Respirable Quartz

The results of gravimetric dust sampling for respirable quartz are presented in Tables 1 and 2 for Series 1, Series 2, Series 3 and Series 4 data with detailed statistical analysis presented in Tables A-2 to A-16 and Figures A-1 to A-9 in Appendix - A. The distributions represent the raw data in $mg/M^3 \times 100$ and the natural logarithms of the data in $\ln (mg/M^3 \times 100)$. Calculation of the best estimate of the mean and the standard deviation are presented in Tables A-1, A-7, A-10 and A-13. Derivation of the results presented in these latter tables will be found in Appendix - F.

Table - 1 Gravimetric Dust Sampling

Respirable Quartz

Series 1 Data

$mg/M^3 \times 100$ N = 872		Ln ($mg/M^3 \times 100$) N = 860		mg/M^3 (1) x 100	
$\bar{X}$	σ	$\bar{X}ln$	σln	$\bar{X}$	σ
10.5	8.4	2.02587	0.77477	10.2	9.3
Antilog		7.58	2.17		

Series 2 Data

$mg/M^3 \times 100$ N - 164		Ln ($mg/M^3 \times 100$) N = 159		mg/M^3 (1) x 100	
$\bar{X}$	σ	$\bar{X}ln$	σln	$\bar{X}$	σ
13.1	10.8	2.2524	0.9960	15.5	19.7
Antilog		9.51	2.71		

(1) Calculation, using lognormal theory, of m a Statistic to estimate the mean $\bar{u}$ and V a Statistic to Estimate $S_{\bar{u}}$.

Table - 2 Gravimetric Dust Sampling

Respirable Quartz

Series 3 Data

mg/M^3 x 100 N = 244		Ln (mg/M^3 x 100) N = 232		mg/M^3 (1) x 100	
$\overline{X}$	σ	$\overline{X}ln$	σln	$\overline{X}$	σ
10.9	10.4	2.10668	0.77435	11.0	9.9
Antilog		8.22	2.17		

Series 4 Data

mg/M^3 x 100 N = 326		Ln (mg/M^3 x 100) N = 261		mg/M^3 (1) x 100	
$\overline{X}$	σ	$\overline{X}ln$	σln	$\overline{X}$	σ
5.51	5.49	1.35105	0.71596	4.96	4.08
Antilog		3.86	2.05	-	-

(1) Calculation, using lognormal theory, of m a Statistic to estimate the mean $\overline{u}$ and V a Statistic to estimate $S_{\overline{u}}$.

Applied Statistical Analysis of Respirable Dust.

The results of gravimetric dust sampling of respirable dust are presented in Tables 3 and 4 for Series 1, Series 2, Series 3 and Series 4 data with detailed statistical analyses presented in Tables B-2, B-3, B-4, B-6, B-7. B-9, B-10, B-11, B-12, B-13, B-14 and B-15 and in Figures B-1 to B-9 Occupational exposures are also presented in Tables B-1, B-5 and B-16 in Appendix - B. These distributions represent the raw data in $mg/M^3 \times 100$ and the natural logarithms of the data in $\ln (mg/M^3 \times 100)$.

Calculation of the best estimate of the mean and the standard deviation are presented in Tables B-2, B-6, B-9, and B-12. Derivation of the results presented in these latter tables will be found in Appendix - F.

Table 3 Gravimetric Dust Sampling

Respirable Dust

Series 1 Data

$mg/M^3 \times 100$ N = 864		Ln ($mg/M^3 \times 100$) N = 862		mg/M^3 (1) x 100	
$\overline{X}$	σ	$\overline{X}ln$	σ_{ln}	$\overline{X}$	σ
49.1	31.6	3.10465	0.77393	29.9	27.1
Antilog		22.30	2.17		

Series 2 Data

$mg/M^3 \times 100$ N = 137		Ln ($mg/M^3 \times 100$) N = 155		mg/M^3 (1) x 100	
$\overline{X}$	σ	$\overline{X}ln$	σ_{ln}	$\overline{X}$	σ
65.5	47.2	4.19274	0.9644	104.6	126.9
Antilog		66.20	2.62		

(1) Calculation, using lognormal theory, of m a Statistic to estimate the mean u and V a Statistic to estimate $S_{\overline{u}}$.

Table 4 Gravimetric Dust Sampling

Respirable Dust

Series 3 Data

$\overline{X}$ mg/M^3 x 100 N = 249		Ln (mg/M^3 x 100) N = 259		mg/M^3 (1) x 100	
$\overline{X}$	σ	$\overline{X}$ln	σln	$\overline{X}$	σ
52.8	36.8	3.80068	0.77033	60.3	54.2
Antilog -		44.73	2.16		

Series 4 Data

mg/M^3 x 100 N = 301		Ln (mg/M^3 x 100) N = 333		mg/M^3 (1) x 100	
$\overline{X}$	σ	$\overline{X}$ln	σln	$\overline{X}$	σ
50.5	30.8	3.76089	0.75667	57.3	2.5
Antilog -		42.98	2.13	-	-

(1) Calculation, using lognormal theory, of m a Statistic to estimate the mean $\bar{u}$ and V a Statistic to estimate $S_{\bar{u}}$.

Applied Statisitcal Analysis of Konimeter Observations.

The results of konimeter sampling are presented in Table 5 for series-1, and series 3 data with detailed statistical analyses presented in tables C-1 to C-4 and in Figures C-1 to C-4 (Appendix C). The distributions represent the raw data in particles per cubic centimeter.

Calculation of the best estimate of the mean and the standard deviation of konimeter observations are presented in Tables E-13 and E-14 with graphical presentation of the log-normal distributions in Tables E-2 and E-4 in Appendix E.

Table 5 Gravimetric Dust Sampling

Konimeter Observations

p.p.c.c.

Data Source	Class Interval	N	$\bar{X}$	σ	CV%
Series - 1	0 - 25	438	191.1	180.2	93.3
Series - 1	0 - 100	438	186.8	186.3	99.7
Series - 1 (1)	-	438	149.8	84.1	56.1
Series - 3	0 - 25	242	283.6	189.4	66.8
Series - 3	0 - 50	242	284.9	188.0	66.2
Series - 3 (1)	-	242	242.1	94.2	38.9

N - Number of Observations

$\bar{X}$ - Arithmetic Mean

σ - Standard Deviation

CV - Coefficient of Variation

(1) Calculation, using lognormal theory of m a Statistic to estimate the mean $\bar{u}$ and V a Statistic for estimate S_u. Appendix E. Tables 13 and 14.

Relative Exposure of Nine Different Occupations in an Ontario Uranium Mine to Respirable Quartz, Respirable Dust and Respirable Combustible Dust.

Small number statistical methods techniques [1][2][3][7][9] have been used to calculate the confidence limits at the 95 per cent probability level for respirable quartz mg/M3, respirable dust mg/M3 x 100 and respirable combustible dust mg/M3 x 100 for the following occupations in an Ontario Uranium mine -: [4] [5] [6] .

- JDT Operator
- Scooptram Operator
- AN/FO Loader Operator
- Mobile Rock Bolt Operator
- Jumbo Drill Operator
- Longhole Driller
- Conveyor Belt Operator
- Rock Breaker Operator
- Mine Shaft Boss

The graphical presentations in Figures D-1, D-2 and D-3 in Appendix D reveal the relative exposures of the various occupations[10]. The upper and lower limits at the 95% confidence level have been plotted. The conveyor belt operator (47) is revealed to have the highest exposure in this group of occupations.

Assessment of the Assumption of Normality of Individual Observations.

Documents having reference to the assumption of normality and log-normality are listed under the References (8), (11) to (15), (21) to (24) and (19). The sources of the tables and graphical presentations is reference (19) in Appendix-E.

Six of the area classifications listed in Table E-1 are presented in Tables E-3 to E-8 for respirable quartz concentrations. These results of computer program studies (16) reveal the observations to be log-normally distributed.

The results of the studies of konimeter observations for series-1 and series-3 data reveal these distributions to be log-normal, at the 0.05 probability level, Figures E-1 to E-4 and Tables E-9 to E-12.

Use of Log-normal Theory to Calculate the Best Estimate of the Mean and the Standard Deviation of Konimeter, Respirable Dust and Respirable Quartz Observations (17)(18)(19)(20).

As described in Appendix E individual observations of respirable quartz, respirable dust and konimeter data have been found to be log-normally distributed.

Studies of log-normal distribution observations (19)(20) have revealed the necessity for further statistical analysis to correct a tendency to underestimate the true value of the mean and standard deviation of a log-normal distribution. The method recommended by Aitchison and Brown (20) and illustrated by Link (19) has been used to calculate the best estimate of the mean and the standard deviation for all of these distributions presented in Appendix A, B, C and E. For a fuller discussion of the method of Aitchison and Brown, refer to Appendix F.

Conclusions

Applied statistical analyses of a large number of respirable quartz, respirable dust and konimeter observations in Ontario uranium mines have revealed the best estimate of the mean and the standard deviation of the concentrations of respirable quartz to be as follows:-

Series	N	$\overline{X}$ mg/M^3	σ mg/M^3
1	860	0.102	0.093
2	159	0.155	0.197
3	232	0.110	0.099
4	261	0.050	0.041

for the concentrations of respirable dust, in the following table

		$\overline{X}$ mg/M^3	σ mg/M^3
1	862	0.299	0.271
2	155	1.046	1.270
3	259	0.060	0.540
4	333	0.057	0.025

and for Konimeter observations in p.p.c.c.

		$\overline{X}$	σ
1	438	149.8	84.1
3	242	242.1	94.2

A study of nine mine occupations has demonstrated the importance of graphical presentation of the 95% confidence limits to reveal the relative exposure of mine workers to respirable quartz, total respirable dust, and combustible dust concentrations. The conveyor belt operator area was found to have the highest concentration.

Appendix - A

Applied Statistical Analysis

of

Respirable Quartz

Observations.

Table A-1

Gravimetric Dust Sampling
Calculation Using Lognormal
Theory, of m, a Statistic to
Estimate the Mean u and
V^2 a statistic to Estimate S^2u
Series - 1 Data
Respirable Quartz
ln (mg/M3 x 100)

Calculation of m		Calculation of V^2	
Notation	Value	Notation	Value
$\bar{u}$	2.02587	$\bar{u}$	2.02587
Su^2	0.600268	Su^2	0.600268
$e^{\bar{u}}$	7.5383	$2\bar{u}$	4.05174
N	860	$e^{2\bar{u}}$	57.397
$T=\frac{1}{2} S_u^2$	0.300134	N	860
$\psi(\frac{1}{2} S_u^2$	1.349	ϕ n (S_u^2)	1.490
m =		V^2	1.490(57.39)
$(e^{\bar{u}})\ \psi\ (\frac{1}{2} S_u^2)$	10.1692	V^2	85.5215
		V =	9.2478
m =	10.17 mg/M3 x 100		9,25 mg/M^3 x 100
=	0.10 mg/M^3	=	0.092 mg/M3

Table A-2

Gravimetric Dust Sampling
Series - 1 Data
Respirable Quartz Concentrations
ln (mg/M^3 x 100)

Class Interval	f	d	fd	fd^2
0.000-0.250	22	-7	-154	1078
0.250-0.500	0	-6	0	0
0.500-0.750	50	-5	-250	1250
0.750-1.000	0	-4	0	0
1.000-1.250	59	-3	-177	531
1.250-1.500	64	-2	-128	256
1.500-1.750	80	-1	- 80	80
1.750-2.000	135	0	-789	-
2.000-2.250	128	1	128	128
2.250-2.500	99	2	198	396
2.500-2.750	77	3	231	693
2.750-3.000	68	4	272	1088
3.000-3.250	28	5	140	700
3.250-3.500	31	6	186	1116
3.500-3.750	6	7	42	294
3.750-4.000	9	8	72	576
4.000-4.250	3	9	27	243
4.250-4.500	0	10	0	0
4.500-4.750	0	11	0	0
4.750-5.000	1	12	12	144
			+1308	

$\varepsilon f = 860$ $\quad \varepsilon fd = 519$ $\quad \varepsilon fd^2 = 8573$

$\bar{x}^1 = 1.875$

$i = 0.250$

Series-1 Data

$N = \varepsilon f = 860$

$\frac{\varepsilon fd}{N} = \frac{519}{860} = 0.0603488$

$\frac{\varepsilon fd^2}{N} = \frac{8573}{860} = 9.968605$

$\frac{(\varepsilon fd)^2}{N} = 0.364198$

$\bar{X} = 1.875 \qquad i = 0.250$

$\frac{\varepsilon fd}{N}(i) = 0.150872$

$\bar{X}_{1n} = \bar{X}^1 + \frac{\varepsilon fd}{N}(i)$

$= 1.875 + 0.150872$

$= 2.025872$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 9.968605 - 0.364198$

$= 9.604407$

$\sigma^1 = 3.099098$

$\sigma = \sigma^1 \times i$

$= 0.250 \times 3.099098$

$= 0.7747744$

$\bar{X}_{1n} = 2.02587_{1n\ (mg/M^3 \times 100)}$

$\sigma_{1n} = 0.77477_{1n\ (mg/M^3 \times 100)}$

$\bar{X} = 7.58270_{mg/M^3} \times 100$

$\sigma = 2.17009_{mg/M^3} \times 100$

Figure A-1

Gravimetric Dust Sampling - Series-1 Data

Respirable Quartz Concentration

ln (mg/M^3 x 100)

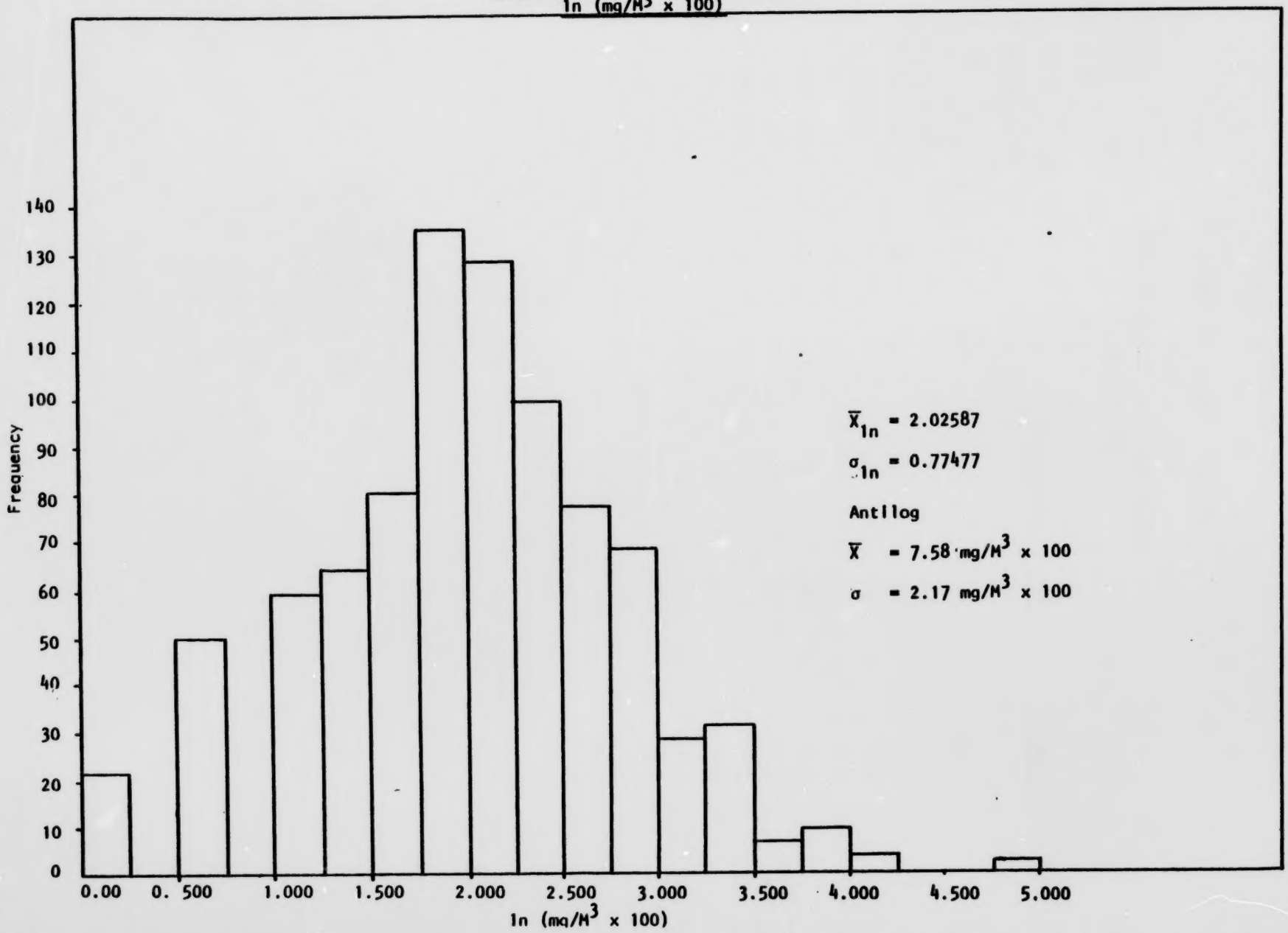


Table A-3

Gravimetric Dust Sampling
Series 1 Data
Respirable Quartz Concentrations
$mg/M^3 \times 100$

Class Interval mg/M3 x 100	f	d	fd	fd^2	f%
0 - 5	193	-1	-193	193	22.1
5 - 10	353	0	0	0	40.5
10 - 15	156	1	156	156	17.9
15 - 20	81	2	162	324	9.3
20 - 25	35	3	105	315	4.0
25 - 30	23	4	92	369	2.6
30 - 35	13	5	65	325	1.5
35 - 40	3	6	18	108	0.3
40 - 45	5	7	35	245	0.6
45 - 50	6	8	48	384	0.7
50 - 55	2	9	18	162	0.2
55 - 60	2	10	20	200	0.2
					99.5

$\varepsilon f = \overline{872}$

$\varepsilon fd = \frac{719}{526}$

$\varepsilon fd^2 = \overline{2781}$

Series 1 Data

$N = \varepsilon f = 872$

$\frac{\varepsilon fd}{N} = \frac{526}{872} = 0.6032$

$\frac{\varepsilon fd^2}{N} = \frac{2781}{872} = 3.1892$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 0.36385$

$\overline{X}^1 = 7.5 \qquad i = 5.0$

$\frac{\varepsilon fd}{N}(i) = 0.6032\ (5)$
$= 3.016$

$\overline{X} = \overline{X}^1 + \frac{\varepsilon fd}{N}(i)$

$= 7.5 + 3.016$
$= 10.516$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 3.1892 - 0.36385$
$= 2.82535$

$\sigma^1 = 1.680877$

$\sigma = 0^1 \times i$
$= 1.6808 \times 5$
$= 8.404$

$\overline{X} = 10.52\ mg/M^3 \times 100$ $\qquad \sigma = 8.40\ mg/M^3 \times 100$

Coefficient of Variation - CV

$CV = \frac{8.40}{10.52} \times 100 = 79.8\%$

Figure A-2
Gravimetric Dust Sampling - Respirable Quartz
Series - 1 Data
$mg/M^3 \times 100$

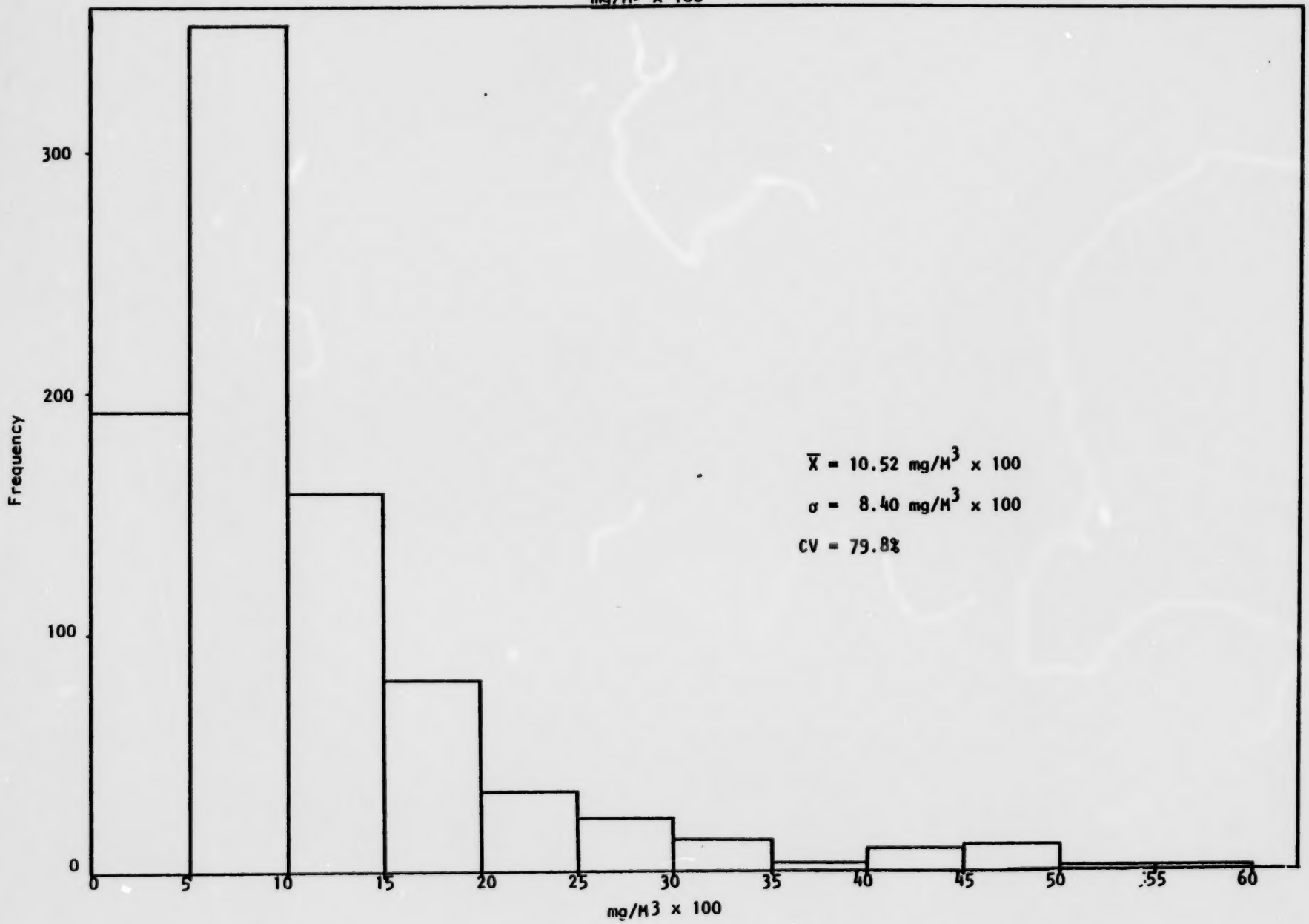


Table A-4

Gravimetric Dust Sampling

Series - 1 Data

Respirable Quartz

$mg/M^3 \times 100$

Occupation	N	$\bar{X}$	σ	CV %
Shift Boss	21	6.52	5.44	83.3
Crushing	4	12.25	12.31	100.5
Rock bolting	42	9.0	5.93	65.9
Shaft Cagetender	12	7.75	4.56	58.8
Drift Trackman	32	11.74	13.76	117.2
Shift Deckman	5	4.6	2.07	45.0
Haulage	68	12.73	9.58	75.24
Mucking	62	9.60	6.70	69.0
Misc Travel	9	7.56	2.35	31.1
Shaft Skiptender	4	8.5	3.87	45.5
Shaft Material	6	10.66	10.58	99.0
	(Observation 32 included)			
	5	6.4	1,81	28.3
	(Observation 32 not included)			
Services:				
Rigger	9	5.67	3.16	55.8
Clean Track	6	7.66	5.28	68.9
Timberman	6	13.3	9.5	71.4
Pipefitting	30	10.5	8.31	78.9
Bulldozer	2	6.5	2.12	32.1
Mechanic	18	15.1	29.58	195.9
	(Observation 136 included)			
	17	8.89	8.18	92.1
	(Observation 136 not included)			
Ditching	6	10.67	9.33	87.5
Electrician	39	4.62	3.18	68.9
General	28	8.53	4.89	57.3
Scaling	1	Observation - 18		

Table A-5

Gravimetric Dust Sampling
Occupation - Drilling
Respirable Quartz
Series 1 Data
$mg/M^3 \times 100$

Class Interval	f	d	fd	fd^2
0 - 5	40	-1	-40	40
5 - 10	87	0	-40	-
10 - 15	26	1	26	26
15 - 20	11	2	22	44
20 - 25	6	3	18	54
25 - 30	0	4	0	0
30 - 35	3	5	15	45
35 - 40	1	6	6	36
40 - 45	1	7	7	49
45 - 50	0	8	0	0
50 - 55	0	9	0	0
55 - 60	0	10	0	0
	$\varepsilon f = 175$		94 $\varepsilon fd = 54$	

$\varepsilon fd^2 = 294$

$i = 5$

$x^1 = 7.5$

$N = \varepsilon f = 175$

$\frac{\varepsilon fd}{N} = \frac{54}{175} = 0.30857$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 0.095216$

$\frac{\varepsilon fd^2}{N} = \frac{294}{175} = 1.68$

$\overline{X}^1 = 7.5$

$\frac{\varepsilon fd}{N}\ (i) = 0.3075$
$= 1.5429$

$\overline{X} = \overline{X}^1 + \frac{\varepsilon fd}{N}\ (i) = 7.5 + 1.5429 = 9.0428$

$(\sigma 1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 1.68 - 0.095$
$= 1.585$

$\sigma^1 = 1.2589$

$\sigma = \sigma^1 \times i$
$= 1.2589 \times 5$
$\sigma = 6.2948$

$\overline{X} = 9.043\ \text{mg/M}^3 \times 100$ $\qquad$ $\sigma = 6.295\ \text{mg/M}^3 \times 100$

$\overline{X} = 0.090\ \text{mg/M}^3$ $\qquad$ $\sigma = 0.063\ \text{mg/M}^3$

Table A-6

Gravimetric Dust Sampling
Occupation - Slushing
Respirable Quartz
Series 1 Data
$mg/M^3 \times 100$

Class Interval	f	d	fd	fd^2
0 - 5	36	-1	-36	36
5 - 10	66	0	-36	-
10 - 15	41	1	41	41
15 - 20	26	2	52	104
20 - 25	8	3	24	72
25 - 30	3	4	12	48
30 - 35	2	5	10	50
35 - 40	1	6	6	36
40 - 45	2	7	14	98
45 - 50	2	8	16	128
50 - 55	1	9	9	81
	$\varepsilon f = 188$		184	
			$\varepsilon fd = -36$	
			148	

$\varepsilon fd^2 = 694$

$\bar{i} = 5.0$

$\bar{X}^1 = 7.5$

$N = \varepsilon f = 188$

$\frac{\varepsilon fd}{N} = \frac{148}{188} = 0.787234$

$\frac{\varepsilon fd^2}{N} = 694$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 0.6197374$

$\overline{X}^1 = 7.5$

$\frac{\varepsilon fd}{N}(i) = 0.787234 \times 5.0$

$\overline{X} = \overline{X}^1 + \frac{\varepsilon fd}{N}(i)$

$= 7.5 + 3.93617$

$= 11.436$

$(\sigma 1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 694 - 0.6197$

$= 693.38$

$\sigma^1 = 26.33$

$\sigma = \sigma^1 \times i$

$\sigma = 131.661$

$\overline{X} = 11.436 \text{ mg/M}^3 \times 100$

$= 0.114 \text{ mg/M}^3$

$\sigma = 131.661 \text{ mg/M}^3 \times 100$

$= 1.317 \text{ mg/M}^3$

Table A-7

Gravimetric Dust Sampling Calculation Using Lognormal Theory, of m, a Statistic to Estimate the Mean u and V^2 a Statistic to Estimate S^2_u

Series - 2 Data

Respirable Quartz
ln (mg/M3 x 100)

Calculation of m		Calculation of V^2		
Notation	Value	Notation		Value
$\bar{u}$	2.25236	$\bar{u}$		2.25236
S^2_u	0.992	S^2_u		0.992
$e^{\bar{u}}$	9.4877	$2\bar{u}$		4.50472
$T=\frac{1}{2} S^2_u$	0.496	$e^{2\bar{u}}$		90.017
N	159	N		159
$\psi(\frac{1}{2} S^2_u)$	1.635	$\phi n(S^2_u)$		4.3089
m =		V^2	=	4.3089(90.03)
$(e^{\bar{u}})\ \psi(\frac{1}{2} S^2_u)$	15.5124	V^2	=	387.87
		V	=	19.695
m =	15.5 mg/M^3 x 100		=	19.70 mg/M^3 x 100
=	0.16 mg/M^3		=	0.20 mg/M^3

Table A-8

Gravimetric Dust Sampling

Series - 2 Data

Respirable Quartz Concentrations

ln (mg/M^3 x 100)

Class Interval ln (mg/M3 x 100)	f	d	fd	fd^2
0.000 - 0.250	7	-8	-56	448
0.250 - 0.500	3	-7	-21	147
0.500 - 0.750	2	-6	-12	72
0.750 - 1.000	8	-5	-40	200
1.000 - 1.250	6	-4	-24	96
1.250 - 1.500	5	-3	-15	45
1.500 - 1.750	10	-2	-20	40
1.750 - 2.000	17	-1	-17	17
2.000 - 2.250	21	0	-205	-
2.250 - 2.500	17	1	17	17
2.500 - 2.750	14	2	28	56
2.750 - 3.000	13	3	39	117
3.000 - 3.250	14	4	56	224
3.250 - 3.500	8	5	40	200
3.500 - 3.750	7	6	42	252
3.750 - 4.000	4	7	28	196
4.000 - 4.250	0	8	0	0
4.250 - 4.500	0	9	0	0
4.500 - 4.750	1	10	10	100
4.750 - 5,000	0	11	0	0
5.000 - 5.250	0	12	0	0
5.250 - 5.500	2	13	26	338
	$\varepsilon f = 159$		$\varepsilon fd = \frac{+286}{81}$	

$\varepsilon fd^2 = \overline{2565}$

$\overline{X} = 2.125$

$i = 0.250$

Series 2 Data

$N = \varepsilon f = 159$

$\frac{\varepsilon fd}{N} = \frac{81}{159} = 0.5094339$

$\frac{\varepsilon fd^2}{N} = \frac{2565}{159} = 16.132075$

$\frac{(\varepsilon fd)^2}{N} = 0.2595229$

$\bar{X}^1 = 2.125 \qquad i = 0.250$

$\frac{\varepsilon fd}{N}(i) = 0.509434 \times 0.250$
$= 0.1273585$

$\bar{X}_{1_n} = \bar{X}^1 + \frac{\varepsilon fd}{N}(i)$

$= 2.125 + 0.1273585$
$= 2.252358$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \frac{(\varepsilon fd)^2}{N}$

$= 16.132075 - 0.259523$
$= 15.872552$

$\sigma^1 = 3.984037$

$\sigma = \sigma^1 \times i$

$= 3.984037 \times 0.250$
$= 0.996009$

$\bar{X}_{1_n} = 2.252236_3$ ln (mg/M^3 x 100)

$\sigma = 0.99600$ ln (mg/M^3 x 100)

$\bar{X} = 9.51_3$ mg/M^3 x 100

$\sigma = 2.71$ mg/M^3 x 100

Figure - A 3

Gravimetric Dust Sampling - Series 2 Data

Respirable Quartz Concentration
ln (mg/M3 x 100)

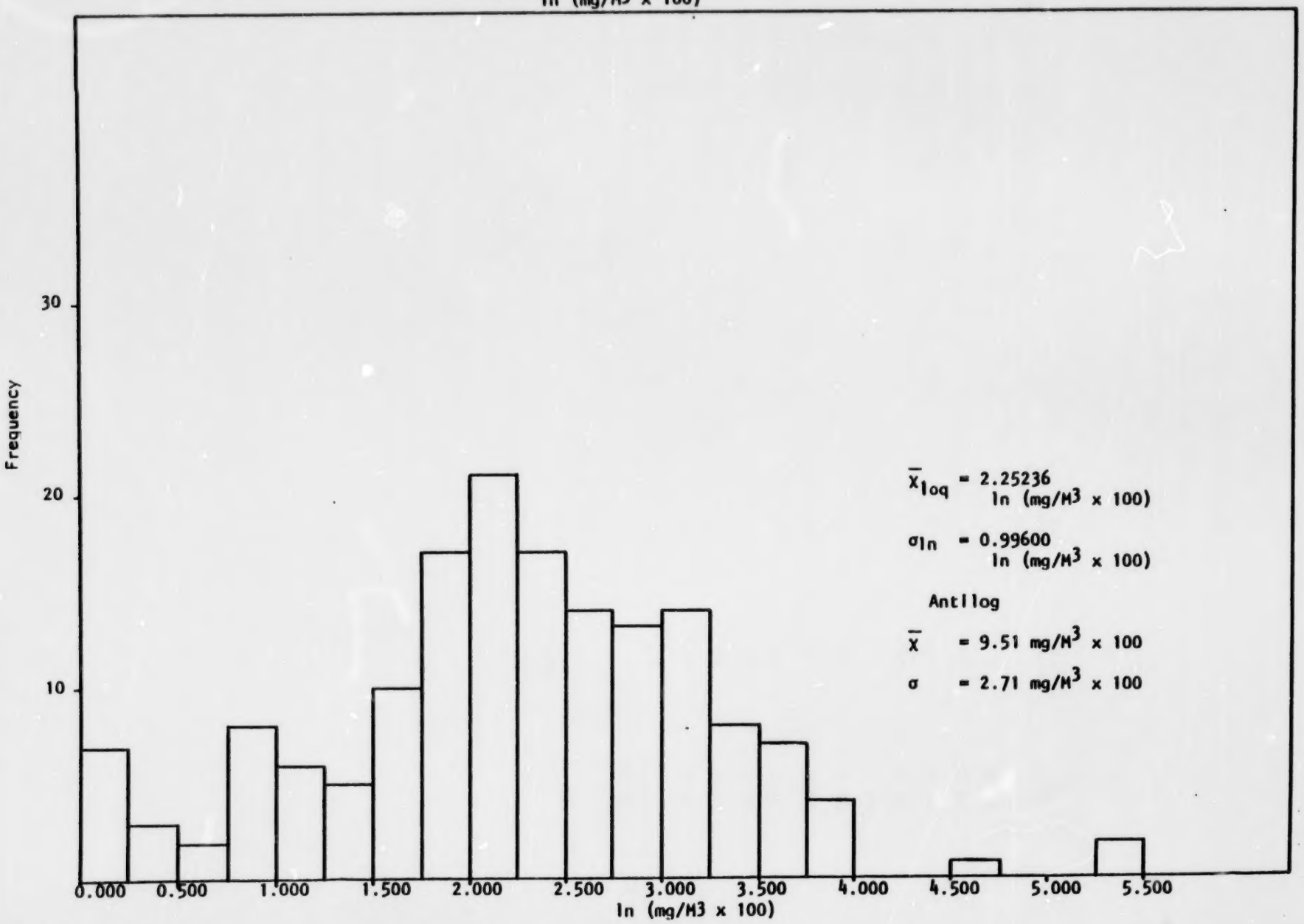


Table - A 9

Gravimetric Dust Sampling

Series - 2 Data

Respirable Quartz Concentrations

$mg/M^3 \times 100$

Class Interval mg/M3 x 100	f	d	fd	fd^2	f%
0 - 5	38	0	0	0	23.17
5 - 10	47	1	47	47	28.66
10 - 15	25	2	50	100	15.24
15 - 20	20	3	60	180	12.20
20 - 25	13	4	52	208	7.93
25 - 30	6	5	30	150	3.66
30 - 35	5	6	30	180	3.05
35 - 40	4	7	28	196	2.43
40 - 45	4	8	32	256	2.43
45 - 50	1	9	9	81	0.61
50 - 55	1	10	10	100	0.61
55 - 60	0	11	0	0	
					99.99

$\varepsilon f = \overline{164}$

$\varepsilon fd = \overline{348}$

$\varepsilon fd^2 = \overline{1498}$

$\bar{x}^1 = 2.5$

$i = 5.0$

Series - 2 Data

$N = \varepsilon f = 164$

$\frac{\varepsilon fd}{N} = \frac{348}{164} = 2.12195$

$\frac{\varepsilon fd^2}{N} = \frac{1498}{164} = 9.13415$

$\frac{(\varepsilon fd)^2}{N} = 4.50267$

$\bar{X}^1 = 2.5 \qquad i = 5.0$

$\frac{\varepsilon fd}{N}(i) = 2.1219 \times 5$

$= 10.6095$

$\bar{X} = \bar{X}^1 = \frac{\varepsilon fd}{N}(i)$

$= 2.5 + 10.6095$

$= 13.11$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \frac{(\varepsilon fd)^2}{N}$

$= 9.134 - 4.503$

$= 4.631$

$\sigma^1 = 2.1519$

$\sigma = \quad \times i$

$= 2.1519 \times 5.0$

$= 10.76$

$\bar{X} = 13.11$ mg/M^3 x 100

$\sigma = 10.76$ mg/M^3 x 100

Coefficient of variation - CV

$CV = \frac{10.76}{13.11} \times 100 = 82.1\%$

Figure A- 4

Gravimetric Dust Sampling
Respirable Quartz Concentration
Series 2 - Data
$mg/M^3 \times 100$

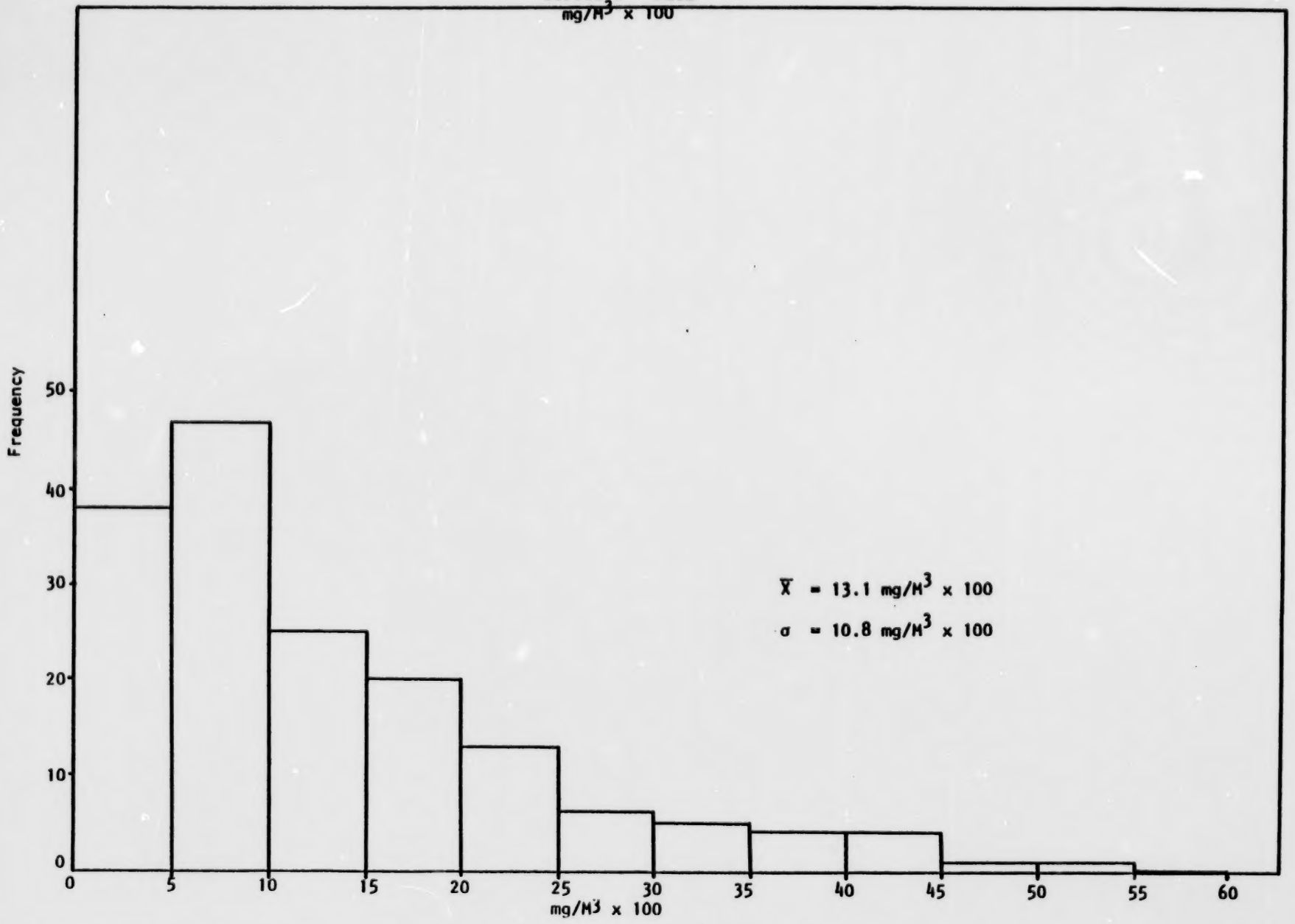


Table - A 10

Gravimetric Dust Sampling
Calculation Using Lognormal
Theory, of m, a Statistic to
Estimate the Mean u and V^2
a Statistic to Estimate S_u^2

Series - 3 Data

Respirable Quartz
$\ln(mg/M^3 \times 100)$

Calculation of m		Calculation of V^2	
Notation	Value	Notation	Value
$\bar{u}$	2.10668	$\bar{u}$	2.10668
S_u^2	0.599618	S_u^2	0.599618
$e^{\bar{u}}$	8.1662	$2\bar{u}$	4.21336
$T = \frac{1}{2} S_u^2$	0.299809	$e^{2\bar{u}}$	67.357
$\psi\ (\frac{1}{2} S_u^2)$	1.347	N	232
		$\phi n\ (S_u^2)$	1.469
$m =$		V^2	1.469(67.357)
$(e^{\bar{u}})\ \psi(\frac{1}{2} S_u^2)$	8.1662(1.347)	V^2	98.9474
		V =	9.9472 $mg/M^3 \times 100$
m =	10.9998		
=	11.0 $mg/M^3 \times 100$		
		=	9.9 $mg/M^3 \times 100$

Table A-11

Gravimetric Dust Sampling

Series - 3 Data

Respirable Quartz

In (mg/M^3 x 100)

Class Interval mg/M^3 x 100	f	d	fd	fd^2
0.000 - 0.250	0	-7	0	0
0.250 - 0.500	0	-6	0	0
0.500 - 0.750	11	-5	-55	275
0.750 - 1.000	1	-4	-4	16
1.000 - 1.250	15	-3	-45	135
1.250 - 1.500	25	-2	-50	100
1.500 - 1.750	28	-1	-28	28
1.750 - 2.000	33	0	-182	-
2.000 - 2.250	23	1	23	23
2.250 - 2.500	32	2	64	128
2.500 - 2.750	17	3	51	153
2.750 - 3.000	21	4	84	336
3.000 - 3.250	6	5	30	150
3.250 - 3.500	6	6	36	216
3.500 - 3.750	8	7	56	392
3.750 - 4.000	3	8	24	192
4.000 - 4.250	1	9	9	81
4.250 - 4.500	2	10	20	200
4.500 - 4.750	0	11	0	0
4.750 - 5.000	0	12	0	0
			+ 397	

$\varepsilon f = 232$

$\varepsilon fd = 215$

$\varepsilon fd^2 = 2425$

$\bar{X} = 1.875$ $\quad i = 0.250$

Series - 3 Data

$N = \varepsilon f = 232$

$\frac{\varepsilon fd}{N} = \frac{215}{232} = 0.9267241$

$\frac{\varepsilon fd^2}{N} = \frac{2425}{232} = 10.452586$

$\frac{(\varepsilon fd)^2}{N} = 0.8588176$

$\overline{X}^1 = 1.875 \qquad i = 0.250$

$\frac{\varepsilon fd}{N}(i) = 0.9267241 \times 0.250$
$= 0.2316810$

$\overline{X}_{ln} = \overline{X}^1_{ln} = \frac{\varepsilon fd}{N}(i)$

$= 1.875 + 0.231681$

$= 2.106681$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \frac{(\varepsilon fd)^2}{N}$

$= 10.452586 - 0.8588176$

$= 9.593768$

$\sigma^1 = 3.097380$

$\sigma_{ln} = \sigma \times i$

$= 3.097380 \times 0.250$

$= 0.774345$

$\overline{X}_{ln} = 2.10668$

ln ($mg/M^3 \times 100$)

$\overline{X} = 8.22$ $mg/M^3 \times 100$

$\sigma_{ln} = 0.77435$

ln ($mg/M^3 \times 100$)

$\sigma = 2.17$ $mg/M^3 \times 100$

Figure - A 5

Gravimetric Dust Sampling - Series 3 Data
Respirable Quartz Concentration
ln (mg/M^3 x 100)

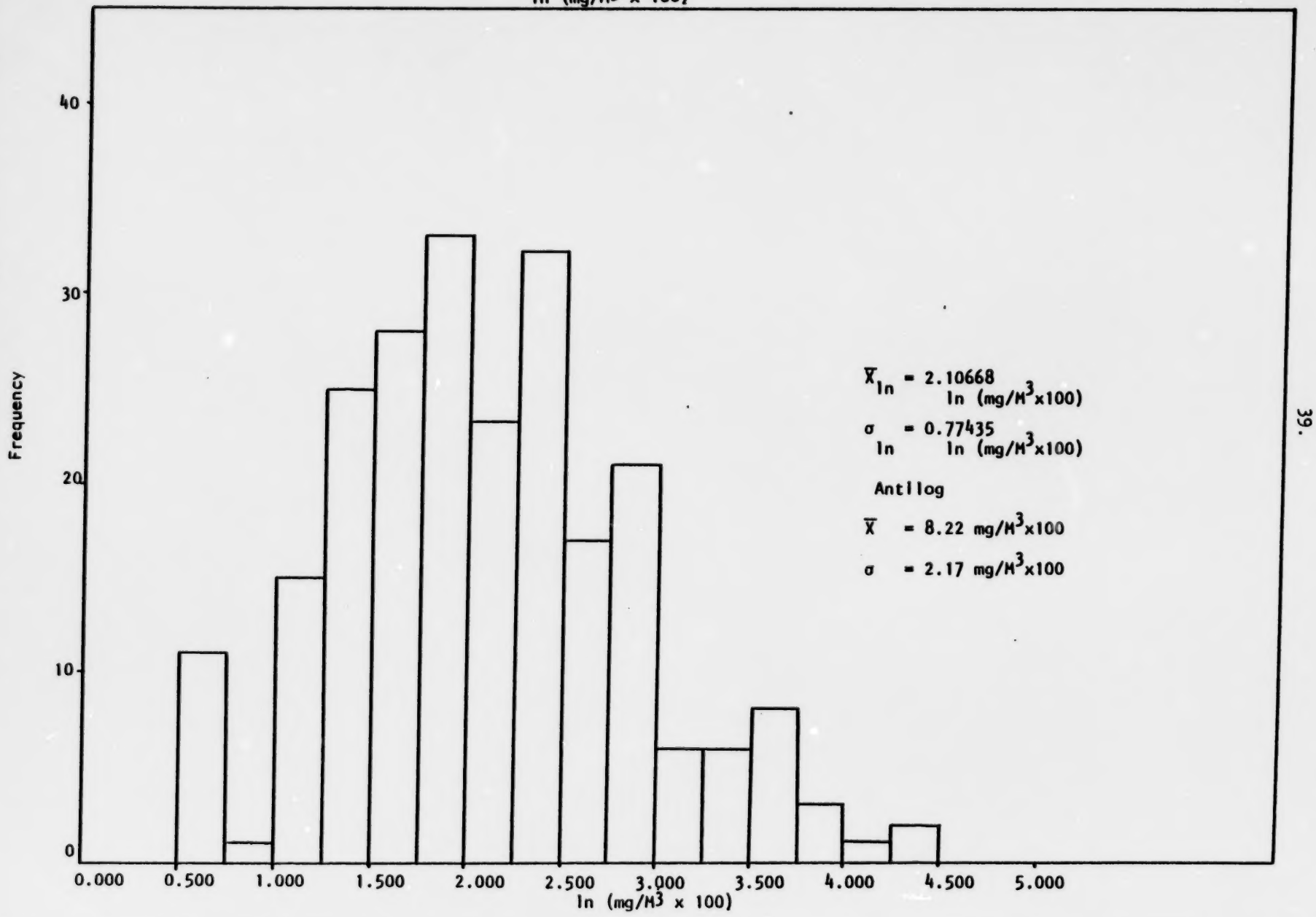


Table - A 12

Gravimetric Dust Sampling

Series - 3 Data

$mg/M^3 \times 100$

Class Interval $mg/M^3 \times 100$	f	d	fd	fd	f%
0 - 5	63	0	0	0	25.82
5 - 10	83	1	83	83	34.02
10 - 15	50	2	100	200	20.49
15 - 20	21	3	63	189	8.61
20 - 25	12	4	48	192	4.92
25 - 30	4	5	20	100	1.64
30 - 35	3	6	18	108	1.23
35 - 40	3	7	21	147	1.23
40 - 45	0	8	0	0	0
45 - 50	2	9	18	162	0.82
50 - 55	0	10	0	0	0
55 - 60	1	11	11	121	0.41
60 - 65	0	12	0	0	0
65 - 70	0	13	0	0	0
70 - 75	1	14	14	196	0.41
75 - 80	0	15	0	0	0
80 - 85	1	16	16	256	0.41
	$\varepsilon f = 244$				100.01

$\varepsilon fd = 412$

$\varepsilon fd^2 = 1754$

$\bar{x}^1 = 2.5$ $\quad i = 5.0$

Series - 3 Data

$N = \varepsilon f = 244$

$\frac{\varepsilon fd}{N} = \frac{412}{244} = 1.68852$

$\frac{\varepsilon fd^2}{N} = \frac{1754}{244} = 7.188525$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 2.85112$

$\overline{X}^1 = 2.5 \qquad i = 5.0$

$\left(\frac{\varepsilon fd}{N}\right) i = 1.68852 \times 5$

$= 8.4426$

$\overline{X} = \overline{X}^1 + \left(\frac{\varepsilon fd}{N}\right) i$

$= 2.5 + 8.4426$

$= 10.9426$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 7.18853 - 2.85112$

$= 4.33740$

$\sigma^1 = 2.0826$

$\sigma = \sigma^1 \times i$

$= 10.413$

$\overline{X} = 10.9 \text{ mg/M}^3 \times 100$

$\sigma = 10.4 \text{ mg/M}^3 \times 100$

Coefficient of Variation - CV

$CV = \frac{10.4}{10.9} \times 100 = 95\%$

Figure - A 6

Gravimetric Dust Sampling Series - 3 Data

Respirable Quartz

$mg/M^3 \times 100$

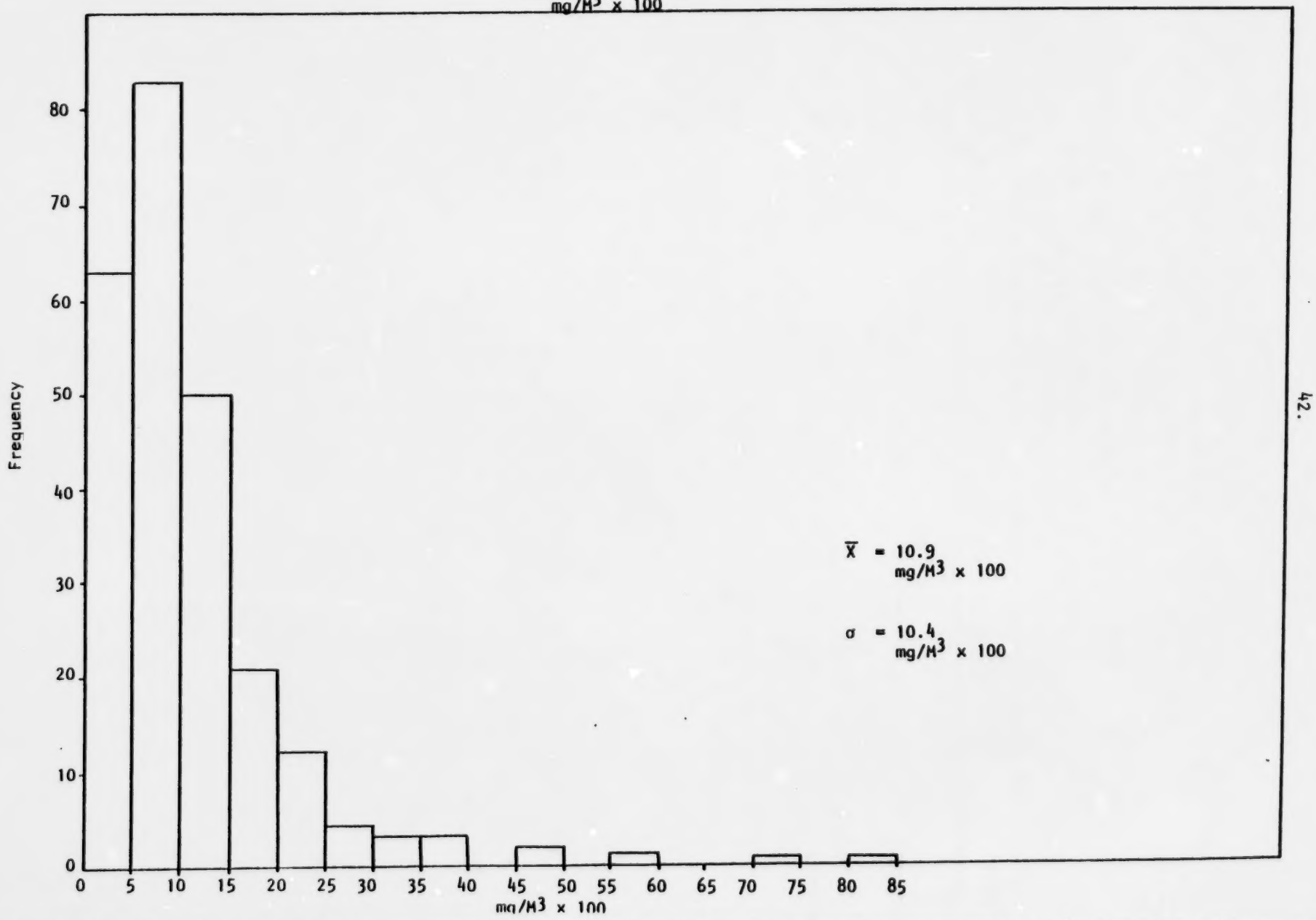


Table - A 13

Gravimetric Dust Sampling Calculation, Using Lognormal Theory, of m a statistic to Estimate the Mean $\bar{u}$ and V^2 a Statistic to Estimate S_u^2. Series - 4 Data

Respirable Quartz $\ln(mg/M^3 \times 100)$

Calculation of m		Calculation of V		
Notation	Value	Notation		Value
$\bar{u}$	1.35105	$\bar{u}$		1.35105
S_u^2	0.5125987	S_u^2		0.5125187
$e^{\bar{u}}$	3.8574	$2u$		2.7021
N	261	e^{2u}		14.880
$T = \frac{1}{2} S_u^2$	0.256299	N		261
$\psi(\frac{1}{2} S_u^2)$	1.289	$\phi n\ (S^2 u)$		1.12033
$m =$				
$(e^{\bar{u}})\ \psi n(\frac{1}{2}S^2 u)$	3.8574 x 1.289	V^2	=	14.880 x 1.12033
		V^2	=	16.6705104
$m =$	4.964878 mg/M^3 x 100	V	=	4.08295 mg/M^3 x 100
				0.041 mg/M^3
	0.049 mg/M^3			

Table - A 14

Gravimetric Dust Sampling

Series - 4 Data

1980

Respirable Quartz

ln (mg/M^3 x 100)

Class Interval	f	d	fd	fd^2
0.000 - 0.250	0	-2	0	0
0.250 - 0.500	0	-1	0	0
0.500 - 0.750	84	0	0	0
0.750 - 1.000	0	1	0	0
1.000 - 1.250	55	2	110	220
1.250 - 1.500	37	3	111	333
1.500 - 1.750	17	4	68	272
1.750 - 2.000	23	5	115	575
2.000 - 2.250	13	6	78	468
2.250 - 2.500	12	7	84	588
2.500 - 2.750	4	8	32	256
2.750 - 3.000	9	9	81	729
3.000 - 3.250	2	10	20	200
3.250 - 3.500	3	11	33	363
3.500 - 3.750	0	12	0	0
3.750 - 4.000	2	13	26	338
4.000 - 4.250	0	14	0	0

$\varepsilon f = \overline{261}$

$\varepsilon fd = \overline{758}$

$\varepsilon fd^2 = \overline{4342}$

Series - 4 Data

$N = \varepsilon f = 261$

$\frac{\varepsilon fd}{N} = \frac{758}{261} = 2.9042145$

$\frac{\varepsilon fd^2}{N} = \frac{4342}{261} = 16.6350153$

$\frac{(\varepsilon fd)^2}{N} = (2.9042145)^2 = 8.43446186$

$\frac{\varepsilon fd}{N}(i) = 2.9042145\ (0.250)$
$= 0.7260536$

$\overline{X}^1_{ln} = \overline{X}^1_{ln} + \frac{\varepsilon fd}{N}(i) = 0.625 + 0.7260536$

$= 1.3510536$

$(\sigma_{ln})^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 16.6360153 - 8.434462$

$= 8.2015533$

$\sigma_{ln} = 2.86383542$

$\sigma_{ln} = \sigma^1_{ln} \times i$

$= 2.8638354 \times 0.250$

$= 0.715959$

$\overline{X}_{ln} = 1.35105_{\ln(mg/M^3 \times 100)}$ $\qquad$ $\sigma_{ln} = 0.71596_{\ln(mg/M^3 \times 100)}$

Antilogarithms

$\overline{X} = 3.861_{mg/M^3 \times 100}$
$= 0.039\ mg/M^3$

$\sigma = 2.046_{mg/M^3 \times 100}$
$= 0.020\ mg/M^3$

Figure - A 7

Gravimetric Dust Sampling - Series 4 Data - 1980

Respirable Quartz

ln (mg/M^3 x 100)

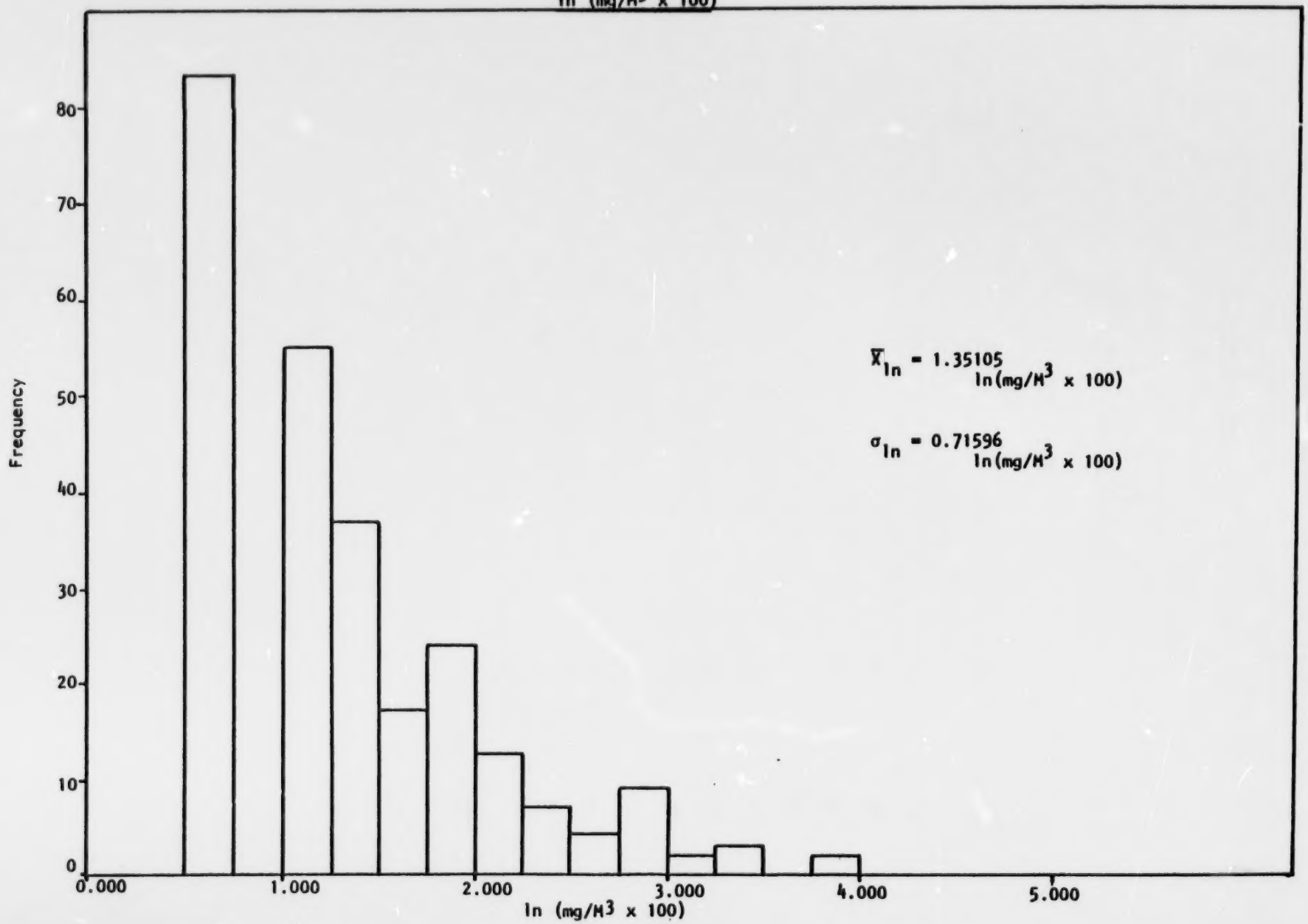


Table - A 15

Gravimetric Dust Sampling

Series - 4 Data

1980

Respirable Quartz

Underground Gravimetric Dust

Sampling

$mg/M^3 \times 100$

Class Interval $mg/M^3 \times 100$	f	d	fd	fd^2
0 - 5	235	0	0	0
5 - 10	58	1	58	58
10 - 15	14	2	28	56
15 - 20	7	3	21	63
20 - 25	3	4	12	48
25 - 30	6	5	30	150
30 - 35	2	6	12	72
35 - 40	0	7	0	0
40 - 45	1	8	8	64
	$\varepsilon f = \overline{326}$		$\varepsilon fd = \overline{169}$	$\varepsilon fd^2 = \overline{511}$

Series - 4 Data

$N = \varepsilon f = 326$

$\frac{\varepsilon fd}{N} = \frac{196}{326} = 0.601227$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 0.36144$

$\frac{\varepsilon fd^2}{N} = \frac{511}{326} = 1.56748$

$\overline{X}^1 = 2.5$ $\qquad \frac{(\varepsilon fd)}{N} i = 0.601227 \times 5 = 3.00614$

$\overline{X} = \overline{X}^1 + \frac{\varepsilon fd}{N} (i)$

$= 2.5 + 3.00614$

$= 5.50614$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 1.56748 - 0.36144$

$= 1.20604$

$\sigma^1 = 1.09819$

$\sigma = \sigma^1 \times 5 = 1.90819 \times 5$

$= 5.49099$

$\overline{X} = 5.51 \text{ mg/M}^3 \times 100$ $\qquad \sigma = 5.49 \text{ mg/M}^3 \times 100$

$= 0.06 \text{ mg/M}^3$ $\qquad = 0.05 \text{ mg/M}^3$

Figure - A 8

Gravimetric Dust Sampling - Series 4 Data - 1980
Respirable Quartz
mg/M3 x 100

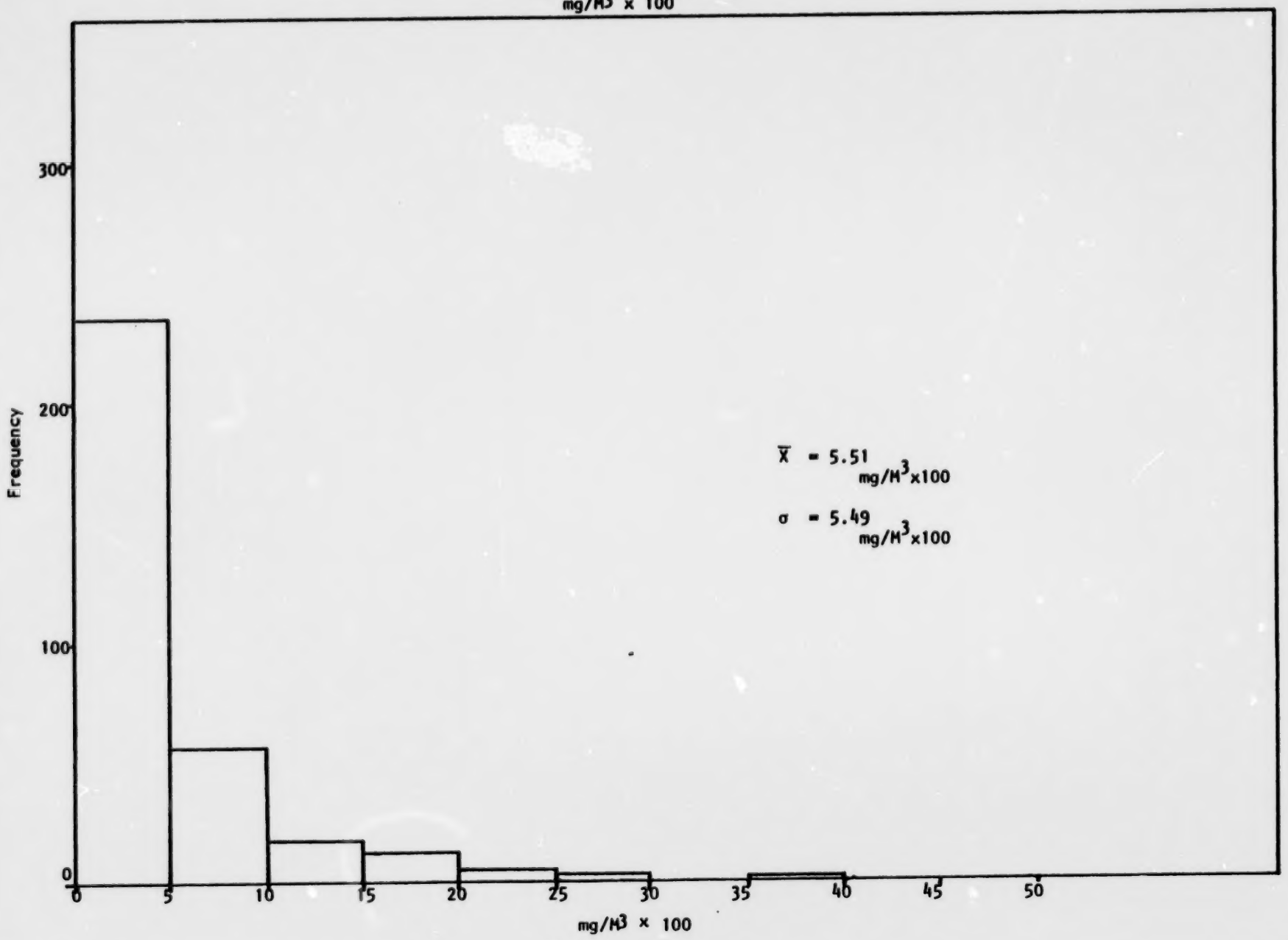


Table - A 16

Gravimetric Dust Sampling

Series - 4 Data

1980

Respirable Quartz

Surface Gravimetric Dust Sampling

$mg/M^3 \times 100$

Class Interval $mg/M^3 \times 100$	f	d	fd	fd^2
0 - 5	32	0	0	0
5 - 10	12	1	12	12
10 - 15	7	2	14	28
15 - 20	5	3	15	45
20 - 25	3	4	12	48
	$\varepsilon f = 59$		$\varepsilon fd = 53$	$\varepsilon fd^2 = 133$

Note: One observation 0.83 mg/M^3
Mandatory Respirator Area.

$N = \varepsilon f = 59$

$\frac{\varepsilon fd}{N} = \frac{53}{59} = 0.8983051$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 0.80695$

$\frac{\varepsilon fd^2}{N} = \frac{133}{59} = 2.254237$

$X^1 = 2.5 \qquad \frac{(\varepsilon fd)}{N} i = 4.491526$

$\overline{X} = \overline{X}^1 + \frac{(\varepsilon fd)}{N} i$

$= 2.5 + 4.491526$

$= 6.992$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 2.254237 - 0.80695$

$= 1.447287$

$\sigma^1 = 1.2030324$

$\sigma = \sigma^1 x\ i$

$= 1.2030 \times 5$

$= 6.0152$

$\overline{X} = 6.99\ mg/M^3 x100$ $\qquad$ $\sigma = 6.02\ mg/M^3 x100$

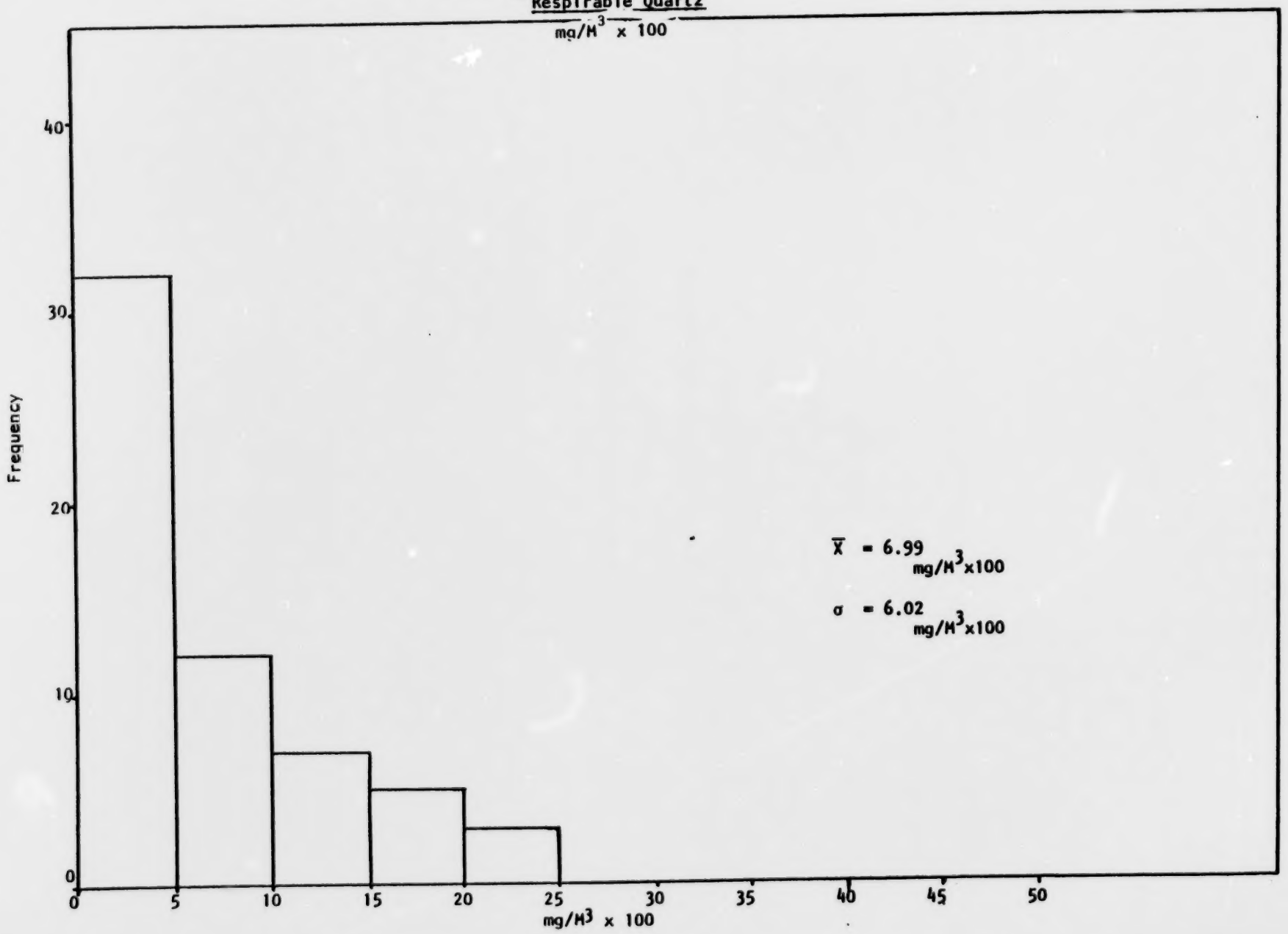
$= 0.07\ mg/M^3$ $\qquad$ $= 0.06\ mg/M^3$

Figure - A 9

Gravimetric Dust Sampling Series - 4 Data - 1980

Surface Observations

Respirable Quartz



Appendix - B

Applied Statistical Analysis

of

Respirable Dust Observations

Table - B 1

Gravimetric Dust Sampling

Occupational Maximum Observations

Respirable Dust

mg/M^3

Series 1, Data

Occupation	Observation
Haulage	0.41
Rockbolting	0.42
Slushing	0.43
Drilling	0.44
Slushing	0.45
Trackman	0.51
Slushing	0.83
Mechanical	1.30

Table - B 2

Gravimetric Dust Sampling
Calculation Using Lognormal
Theory, of m, a Statistic to
Estimate the Mean u and
V^2 a Statistic to Estimate S_u^2
Series - 1 Data
Respirable Dust
Tn ($mg/M^3 \times 100$)

Calculation of m		Calculation of V^2	
Notation	Value	Notation	Value
$\bar{u}$	3.10465	$\bar{u}$	3.10465
S_u^2	0.598963	S_u^2	0.598963
$e^{\bar{u}}$	22.198	$2\bar{u}$	6.02930
N	862	$e^{2\bar{u}}$	492.75
$T = \frac{1}{2} S_u^2$	0.29948	N	862
ψ ($\frac{1}{2}$ Su)	1.349	$\phi_n (S_u^2)$	1.494
$m = (e^{\bar{u}})\ \psi(\frac{1}{2} S_u^2)$	22.198 x 1.349	$V^2 = e^{2\bar{u}}\ \phi_n$ (Su)	492.75(1.494)
		$V^2 =$	736.1685
m =	29.945 $mg/M^3 \times 100$	V =	27.132 $mg/M^3 \times 100$
=	0.30 mg/M^3	=	0.27 mg/M^3

Table - B 3

Gravimetric Dust Sampling

Series 1, Data

Respirable Dust Concentrations

ln (mg/M^3 x 100)

Class Interval	f	d	fd	fd
0.000 - 0.250	5	-15	-75	1125
0.250 - 0.500	0	-14	- 0	0
0.500 - 0.750	1	-13	-13	169
0.750 - 1.000	0	-12	- 0	0
1.000 - 1.250	2	-11	-22	242
1.250 - 1.500	3	-10	-30	300
1.500 - 1.750	3	- 9	-27	243
1.750 - 2.000	8	- 8	-64	512
2.000 - 2.250	6	- 7	-42	294
2.250 - 2.500	16	- 6	-96	576
2.500 - 2.750	22	- 5	-110	550
2.750 - 3.000	70	- 4	-280	1120
3.000 - 3.250	68	- 3	-204	612
3.250 - 3.500	108	- 2	-216	432
3.500 - 3.750	121	- 1	-121	121
3.750 - 4.000	138	0	-1300	-
4.000 - 4.250	110	1	110	110
4.250 - 4.500	77	2	154	308
4.500 - 4.750	47	3	141	423
4.750 - 5.000	26	4	104	416
5.000 - 5.250	17	5	85	425
5.250 - 5.500	6	6	36	216
5.500 - 5.750	6	7	42	294
5.750 - 6.000	1	8	8	64
6.000 - 6.250	0	9	0	0
6.250 - 6.500	0	10	0	0
6.500 - 6.750	1	11	11	121
6.750 - 7.000	0		+ 691	
εf =	862			

εfd = - 609

εfd^2 = 8673

$\bar{X}^1$ = 3.875

i = 0.250

Series - 1 Data

$N = \varepsilon f = 862$

$\frac{\varepsilon fd}{N} = \frac{-609}{860} = -0.7081395$

$\frac{\varepsilon fd^2}{N} = \frac{8673}{860} = 10.084883$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 0.5014616$

$\overline{X}^1 = 3.875 \qquad i = 0.250$

$\frac{\varepsilon fd}{N}(i) = -0.7081395 \times 0.250$

$= -0.177035$

$\overline{X}_{ln} = \overline{X}^1 - \frac{\varepsilon fd}{N}(i)$

$= 3.875 - 0.77035$

$= 3.10465$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 10.084883 - 0.5014616$

$= 9.583421$

$\sigma^1 = 3.095710$

$\sigma = \sigma^1 \times i$

$= 3.09571 \times 0.250$

$= 0.773927$

$\overline{X}_{ln} = 3.10465$ ln ($mg/M^3 \times 100$)

$\sigma_{ln} = 0.773927$ ln ($mg/M^3 \times 100$)

$\overline{X} = 22.3$ $mg/M^3 \times 100$

$\sigma = 2.2$ $mg/M^3 \times 100$

Figure - B 1
Gravimetric Dust Sampling - Series 1 Data
Respirable Dust Concentrations
ln (mg/M^3 x 100)

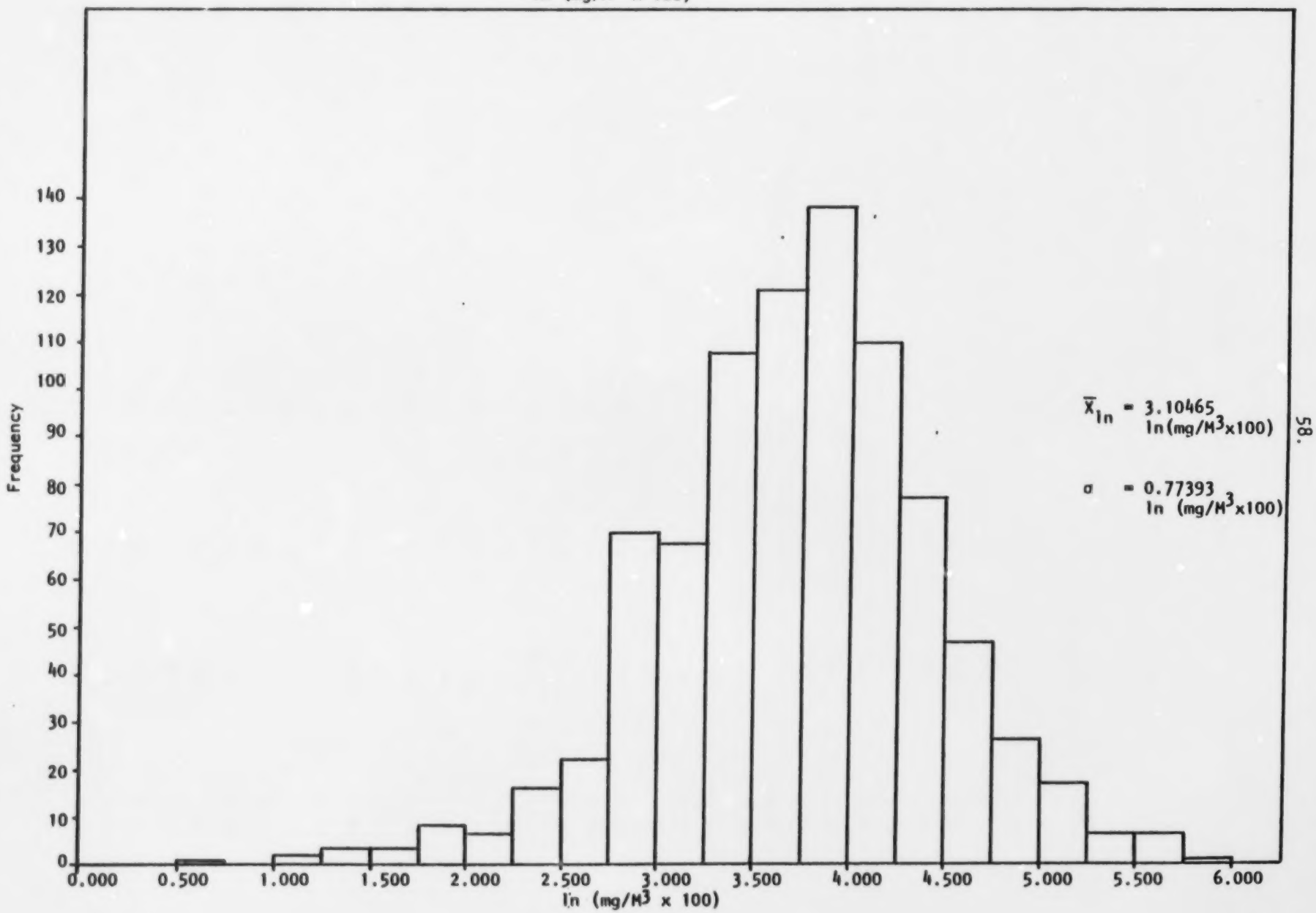


Table - B 4

Gravmietric Dust Sampling

Series 1 Data

Respirable Dust Concentrations

$mg/M^3 \times 100$

Class Interval $mg/M^3 \times 100$	f	d	fd	fd	f%
0 - 5	11	-8	-88	704	1.29
5 - 10	18	-7	-126	882	2.11
10 - 15	33	-6	-198	1188	3.86
15 - 20	64	-5	-320	1600	7.49
20 - 25	73	-4	-292	1168	8.55
25 - 30	74	-3	-222	666	8.67
30 - 35	63	-2	-126	252	7.38
35 - 40	62	-1	-62	62	7.26
40 - 45	76	0	-1434	0	8.90
45 - 50	61	1	61	61	7.14
50 - 55	47	2	91	188	5.50
55 - 60	42	3	126	378	4.92
60 - 65	37	4	148	592	4.33
65 - 70	31	5	155	775	3.63
70 - 75	28	6	168	1008	3.28
75 - 80	17	7	119	833	1.99
80 - 85	18	8	144	1152	2.11
85 - 90	15	9	135	1215	1.76
90 - 95	12	10	120	1200	1.41
95 - 100	13	11	143	1573	1.52
100 - 105	19	12	228	2736	2.22
105 - 110	4	13	52	676	0.47
110 - 115	8	14	112	1568	0.94
115 - 120	7	15	105	735	0.82
120 - 125	0	16	0	0	0
125 - 130	5	17	85	1445	0.59
130 - 135	5	18	90	1620	0.59
135 - 140	5	19	95	1805	0.59
140 - 145	2	20	40	800	0.23
145 - 150	3	21	63	1323	0.35
150 - 155	1	22	22	484	0.12
155 - 160	1	23	23	529	0.12

160 - 165	1	24	24	576	0.12
165 - 170	1	25	25	625	0.12
170 - 175	1	26	26	676	0.12
175 - 180	0	27	0	0	0.00
180 - 185	5	28	140	3929	0.29
185 - 190	0	29	0	0	0.00
190 - 195	1	30	30	900	0.12

Outlying Observations

208, 227, 246, 254, 273, 373, 381, 690

$cf = 864$

$+ \underline{\quad 8}$

Outlying Observation 872

$\overline{2570}$

$- \underline{1434}$

$cfd = 1136$

$\overline{100.86}$

$cfd^2 = \overline{35924}$

$\bar{X}^1 = 42.5$

$i = 5.0$

Series - 1 Data

$N = \varepsilon f = 864$

$$\frac{\varepsilon fd}{N} = \frac{1136}{864} = 1.3148148$$

$$\frac{\varepsilon fd^2}{N} = \frac{35924}{864} = 41.57870$$

$$\left(\frac{\varepsilon fd}{N}\right)^2 = 1.72786$$

$\bar{X}^1 = 42.5 \qquad i = 5.0$

$$\frac{\varepsilon fd}{N}(i) = 1.3148148\ (5.0)$$

$$= 6.574074$$

$$\bar{X} = \bar{X}^1 + \frac{\varepsilon fd}{N}(i)$$

$$= 42.5 + 6.57417$$

$$= 49.074$$

$$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$$

$$= 41.5787 - 1.72786$$

$$= 39.851$$

$\sigma^1 = 6.312752$

$\sigma = \sigma^1 \times i$

$= 6.312752 \times 5$

$= 31.5637$

$\bar{X} = 49.1$ mg/M^{3}x100 $\qquad \sigma = 31.6$ mg/M^{3}x100

Coefficient of Variation - CV

$$CV = \frac{31.6}{49.1} \times 100 = 64.4\%$$

Figure - B 2

Gravimetric Dust Sampling - Respirable Dust

Series 1 Data

$mg/M^3 \times 100$

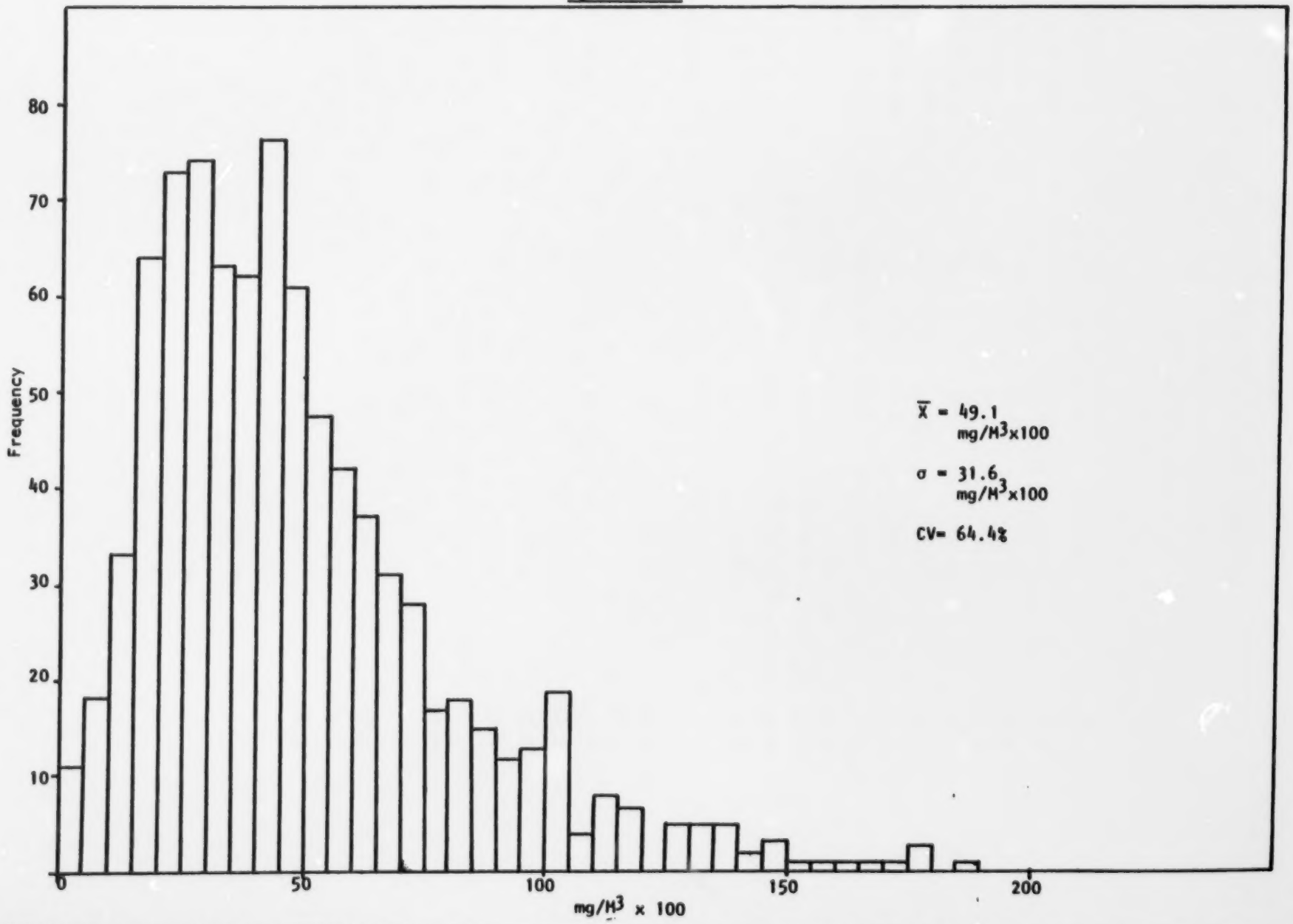


Table - B 5

Gravimetric Dust Sampling

Series - 1 Data

Respirable Dust

$mg/M^3 \times 100$

Occupation	N	$\bar{X}$	σ	CV(1) %
Shift Boss	21	30.57	15.11	49.4
Crushing	4	38.75	36.76	95.0
Rockbolting	42	51.17	46.34	90.6
Shaft Cagetender	12	46.5	14.73	31.7
Drift Trackman	32	43.39	26.05	60.0
Shft Deckman	5	77.6	59.8	77.1
Haulage	68	55.4	39.3	70.9
Mucking	62	70.8	49.4	70.0
Misc Travel	9	43.78	26.86	61.2
Shaft Skiptender	4	52.25	17.73	34.0
Shaft Material	6	49.5	18.3	36.9
Services:				
Rigger	9	22.36	10.78	48.2
Clean Track	6	32.2	8.92	27.7
Timberman	6	60.2	61.2	181.0
Pipefitting	30	67.42	30.03	44.5
Bulldozer	2	93.5	12.02	12.8
Mechanic	18	44.3	22.33	50.4
		(Observations 273 and 373 not included)		
	21	67.4	82.89	122.9
		(Observations 273 and 373 included)		
Ditching	6	76.7	79.2	103.2
Electrician	39	60.97	70.93	116.3
General	28	48.6	21.4	44.0
Scaling	1	Observation - 72.		

(1) CV = Coefficient of Variation = $\frac{\sigma}{\bar{X}} \times 100$

Table - B 6

Gravimetric Dust Sampling Calculation Using Lognormal Theory, of m, a Statistic to Estimate the Mean u and V^2 a Statistic to Estimate Su^2

Series - 2 Data

Respirable Dust

ln (mg/M^3 x 100)

Calculation of m		Calculation of V^2	
Notation	Value	Notation	Value
$\bar{u}$	4.19274	$\bar{u}$	4.19274
Su^2	0.93006	Su^2	0.93006
$e^{\bar{u}}$	66.023	$2\bar{u}$	8.38548
$T = \frac{1}{2} Su^2$	0.46503	$e^{2\bar{u}}$	4359.0
N	155	N	155
$\psi(\frac{1}{2} Su^2)$	1.585	$\phi n(Su^2)$	3.699
$m =$		V^2	3.699 x 4359.0
$(e^{\bar{u}})\ \psi(\frac{1}{2} Su^2)$	104.646		
		$V^2 =$	16123.94
$m =$	104.6 $mg/M^3 x100$	$V =$	126.98 $mg/M^3 x100$
$=$	1.05 mg/M^3	$=$	1.27 mg/M^3

Table - B 7

Gravimetric Dust Sampling

Series - 2 Data

Respirable Dust Concentrations

in (mg/M^3 x 100)

Class Interval	f	d	fd	fd^2
0.000 - 0.250	0	-13	0	
0.250 - 0.500	0	-12	0	
0.500 - 0.750	0	-11	0	
0.750 - 1.000	0	-10	0	
1.000 - 1.250	0	- 9	0	
1.250 - 1.500	0	- 8	0	
1.500 - 1.750	2	- 7	-14	98
1.750 - 2.000	2	- 6	-12	72
2.000 - 2.250	0	- 5	0	0
2.250 - 2.500	1	- 4	- 4	16
2.500 - 2.750	2	- 3	- 6	18
2.750 - 3.000	6	- 2	-12	24
3.000 - 3.250	5	- 1	- 5	5
3.250 - 3.500	19	0	-53	-
3.500 - 3.750	18	1	18	18
3.750 - 4.000	16	2	32	64
4.000 - 4.250	16	3	48	144
4.250 - 4.500	15	4	60	240
4.500 - 4.750	8	5	40	200
4.750 - 5.000	9	6	54	324
5.000 - 5.250	11	7	77	539
5.250 - 5.500	12	8	96	768
5.500 - 5.750	6	9	54	486
5.750 - 6.000	1	10	10	100
6.000 - 6.250	4	11	44	484
6.250 - 6.500	0	12	0	0
6.500 - 6.750	1	13	13	169
6.750 - 7.000	1	14	14	196
	$\varepsilon f = 155$		$+ 560$	
			$\varepsilon fd = 507$	

$\varepsilon fd^2 = 3965$

$\bar{X}^1 = 3.375$ $\quad i = 0.250$

Series - 2 Data

$N = \varepsilon f = 155$

$\frac{\varepsilon fd}{N} = \frac{507}{155} = 3.2709677$

$\frac{\varepsilon fd^2}{N} = \frac{3965}{155} = 25.580645$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 10.699229$

$\overline{X}^1 = 3.375 \qquad i = 0.250$

$\frac{\varepsilon fd}{N}(i) = 3.270968 \times 0.250$
$= 0.817742$

$\overline{X}_{ln} = \overline{X}^1 + \frac{\varepsilon fd}{N} i$

$= 3.375 + 0.817742$
$= 4.19274$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 25.58065 - 10.69923$
$= 14.88142$

$\sigma^1 = 3.857644$

$\sigma = \sigma^1 \times i$
$= 3.857644 \times 0.250$
$= 0.9644$

$\overline{X}_{ln} = 4.19274$ ln ($mg/M^3 \times 100$)

$\sigma_{ln} = 0.9644$ ln ($mg/M^3 \times 100$)

$\overline{X} = 66.20$ $mg/M^3 \times 100$

$\sigma = 2.62$ $mg/M^3 \times 100$

Figure - B 3

Gravimetric Dust Sampling - Series 2 Data

Respirable Dust Concentrations

$mg/M^3 \times 100$

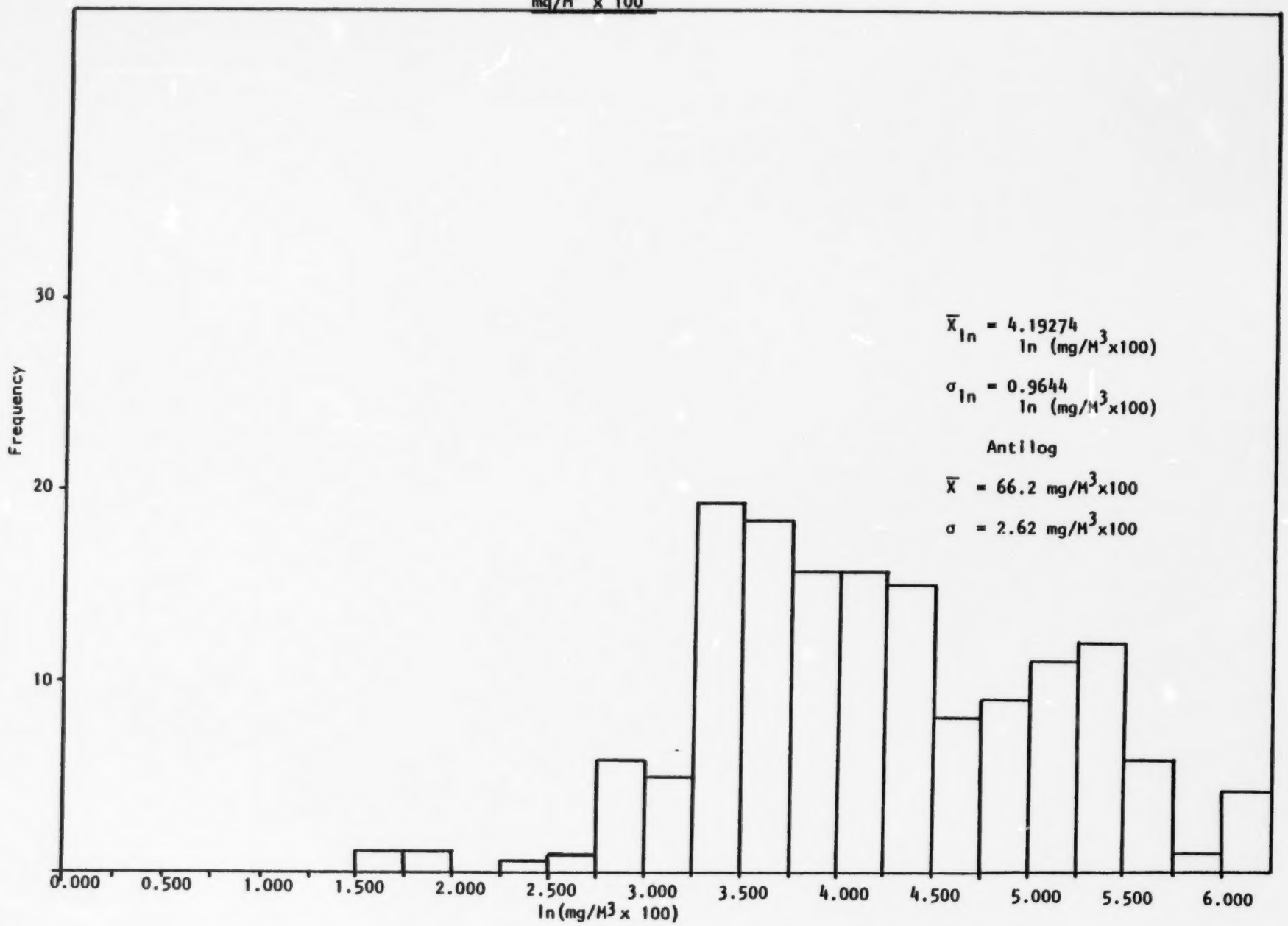


Table - B 8

Gravimetric Dust Sampling

Series 2 Data

Respirable Dust Concentrations

$mg/M^3 \times 100$

Class Interval $mg/M^3 \times 100$	f	d	fd	fd^2	f%
0 - 5	0	-7	0	0	-
5 - 10	4	-6	-24	144	2.92
10 - 15	2	-5	-10	50	1.46
15 - 20	7	-4	-28	112	5.11
20 - 25	7	-3	-21	63	5.11
25 - 30	8	-2	-16	32	5.84
30 - 35	13	-1	-13	13	9.49
35 - 40	14	0	-112	0	10.22
40 - 45	6	1	6	6	4.38
45 - 50	9	2	18	36	6.57
50 - 55	4	3	12	36	2.92
55 - 60	5	4	20	80	3.65
60 - 65	8	5	40	200	5.84
65 - 70	4	6	24	144	2.92
70 - 75	4	7	28	196	2.92
75 - 80	4	8	32	256	2.92
80 - 85	7	9	63	567	5.11
85 - 90	0	10	0	0	0
90 - 95	5	11	55	605	3.65
95 - 100	0	12	0	0	0
100 - 105	3	13	39	507	2.19
105 - 110	1	14	14	196	0.73
110 - 115	0	15	0	0	0
115 - 120	1	16	16	256	0.73
120 - 125	2	17	34	578	1.46
125 - 130	1	18	18	324	0.73
130 - 135	2	19	38	722	1.46
135 - 140	1	20	20	400	0.73
140 - 145	0	21	0	0	0
145 - 150	1	22	22	484	0.73
150 - 155	2	23	46	1058	1.46

Series 2 Data

Class Interval	f	d	fd	fd^2	f%
155 - 160	2	24	48	1152	1.46
160 - 165	2	25	50	1250	1.46
165 - 170	2	26	52	1352	1.46
170 - 175	1	27	27	729	0.73
175 - 180	0	28	0	0	0
180 - 185	1	29	29	841	0.73
185 - 190	0	30	0	0	0
190 - 195	1	31	31	961	0.73
195 - 200	2	32	64	2048	1.46
200 - 205	1	33	33	1089	0.73
					100.28

$\varepsilon f = 137$

$\varepsilon fd = 879$

-112

$\varepsilon fd = 767$ $\varepsilon fd^2 = 16487$

Outlying Observations Greater than 205 mg/M^3 x 100

211, 226, 226, 234, 242, 253, 277, 278, 280, 284,

301, 328, 328, 410.3, 435, 736.3, 791.5, 1050.9.

Series - 2 Data

$N = \varepsilon f = 137$

$\frac{\varepsilon fd}{N} = \frac{767}{137} = 5.59850$

$\frac{\varepsilon fd^2}{N} = \frac{16487}{137} = 120.34306$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 31.343202$

$\overset{1}{X} = 37.5 \qquad i = 5.0$

$\frac{\varepsilon fd}{N}(i) = 27.9925$

$\overline{X} = \overset{1}{X} + \frac{\varepsilon fd}{N}(i)$

$= 37.5 + 27.9925$

$= 65.4925$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 120.3431 - 31.3432$

$= 88.9999$

$\sigma^1 = 9.4339$

$\sigma = \sigma^1 \times i$

$= 9.4339 \times 5$

$= 47.169$

$\overline{X} = 65.49 \text{ mg/M}^3 \times 100 \qquad \sigma = 47.17 \text{ mg/M}^3 \times 100$

Coefficient of Variation - CV

$CV = \frac{47.17}{65.49} \times 100 = 72.0\%$

Figure - B 4

Gravimetric Dust Sampling

Respirable Dust Concentrations

Series - 2 Data

$mg/M^3 \times 100$

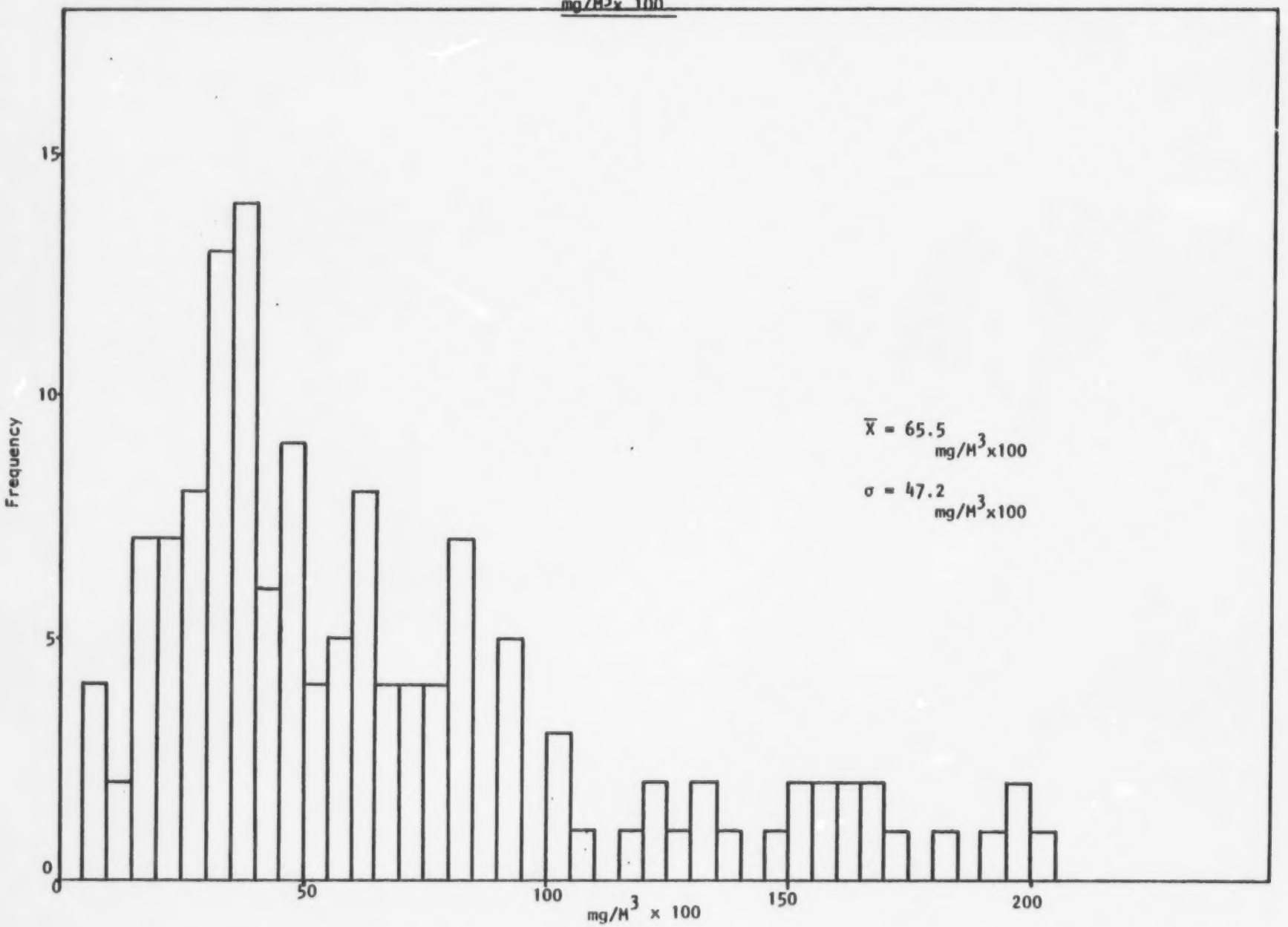


Table - B 9
Gravimetric Dust Sampling
Calculation Using Lognormal
Theory, of m, a Statistic to
Estimate the Mean u and V^2
a Statistic to Estimate S_u^2
Series - 3 Data
Respirable Dust
$\ln (mg/M^3 \times 100)$

Calculation m		Calculation of V^2	
Notation	Value	Notation	Value
$\bar{u}$	3.80068	$\bar{u}$	3.80068
S_u^2	0.59340	S_u^2	0.59340
$e^{\bar{u}}$	44.701	$2\bar{u}$	7.60136
$T = \frac{1}{2} S_u^2$	0.2967	$e^{2\bar{u}}$	1998.2
$\psi(\frac{1}{2} S_u^2)$	1.348	N	259
		$\phi n (S_u^2)$	1.469
$m =$		V^2	1998.2 x 1.469
$(e^{\bar{u}}) \quad \psi(\frac{1}{2}S_u^2)$	60.2569	V^2	2936.356
$m =$	60.2569	$V =$	54.1789
$=$	60.3 $mg/M^3 \times 100$	$=$	54.2 $mg/M^3 \times 100$

Table - B 10

Gravimetric Dust Sampling

Series - 3 Data

Respirable Dust

ln (mg/M^3 x 100)

Class Interval $mg/M^3 x 100$	f	d	fd	fd^2
0.000 - 0.250	0			
0.250 - 0.500	0			
0.500 - 0.750	0			
0.750 - 1.000	0			
1.000 - 1.250	0			
1.250 - 1.500	1	-8	-8	64
1.500 - 1.750	1	-7	-7	49
1.750 - 2.000	2	-6	-12	72
2.000 - 2.250	1	-5	-5	25
2.250 - 2.500	2	-4	-8	32
2.500 - 2.750	12	-3	-36	108
2.750 - 3.000	18	-2	-36	72
3.000 - 3.250	24	-1	-24	24
3.250 - 3.500	31	0	-136	
3.500 - 3.750	26	1	26	26
3.750 - 4.000	45	2	90	180
4.000 - 4.250	33	3	99	297
4.250 - 4.500	15	4	60	240
4.500 - 4.750	22	5	110	550
4.750 - 5.000	10	6	60	360
5.000 - 5.250	5	7	35	245
5.250 - 5.500	6	8	48	384
5.500 - 5.750	2	9	18	162
5.750 - 6.000	2	10	20	200
6.000-6.250	1	11	11	121
			+ 577	

$\varepsilon f = 259$

$\varepsilon fd = 441$

$\varepsilon fd^2 = 3210$

$\bar{X}_{ln} = 3.375$

$i = 0.250$

Series - 3 Data

$N = \varepsilon f = 259$

$\frac{\varepsilon fd}{N} = \frac{441}{259} = 1.7027027$

$\frac{\varepsilon fd^2}{N} = \frac{3210}{259} = 12.393822$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 2.8991965$

$\overline{X1} = 3.375 \qquad i = 0.250$

$\frac{\varepsilon fd}{N}(i) = 1.702703 \times 0.250$

$= 0.425676$

$\overline{X}_{ln} = \overline{X1}_{ln} + \frac{\varepsilon fd}{N}(i)$

$= 3.375 + 0.425676$

$= 3.80068$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 12.393822 - 2.8991965$

$= 9.4946259$

$\sigma^1 = 3.0813350$

$\sigma_{ln} = \sigma^1 \times i$

$= 0.770333$

$\overline{X}_{ln} = 3.80068$ Ln $(mg/M^3 \times 100)$ $\qquad \sigma_{ln} = 0.77033$

$\overline{X} = 44.73$ $mg/M^3 \times 100$ $\qquad \sigma = 2.16$ $mg/M^3 \times 100$

Figure - B 5

Gravimetric Dust Sampling - Series 3 Data

Respirable Dust Concentration

ln (mg/M^3 x 100)

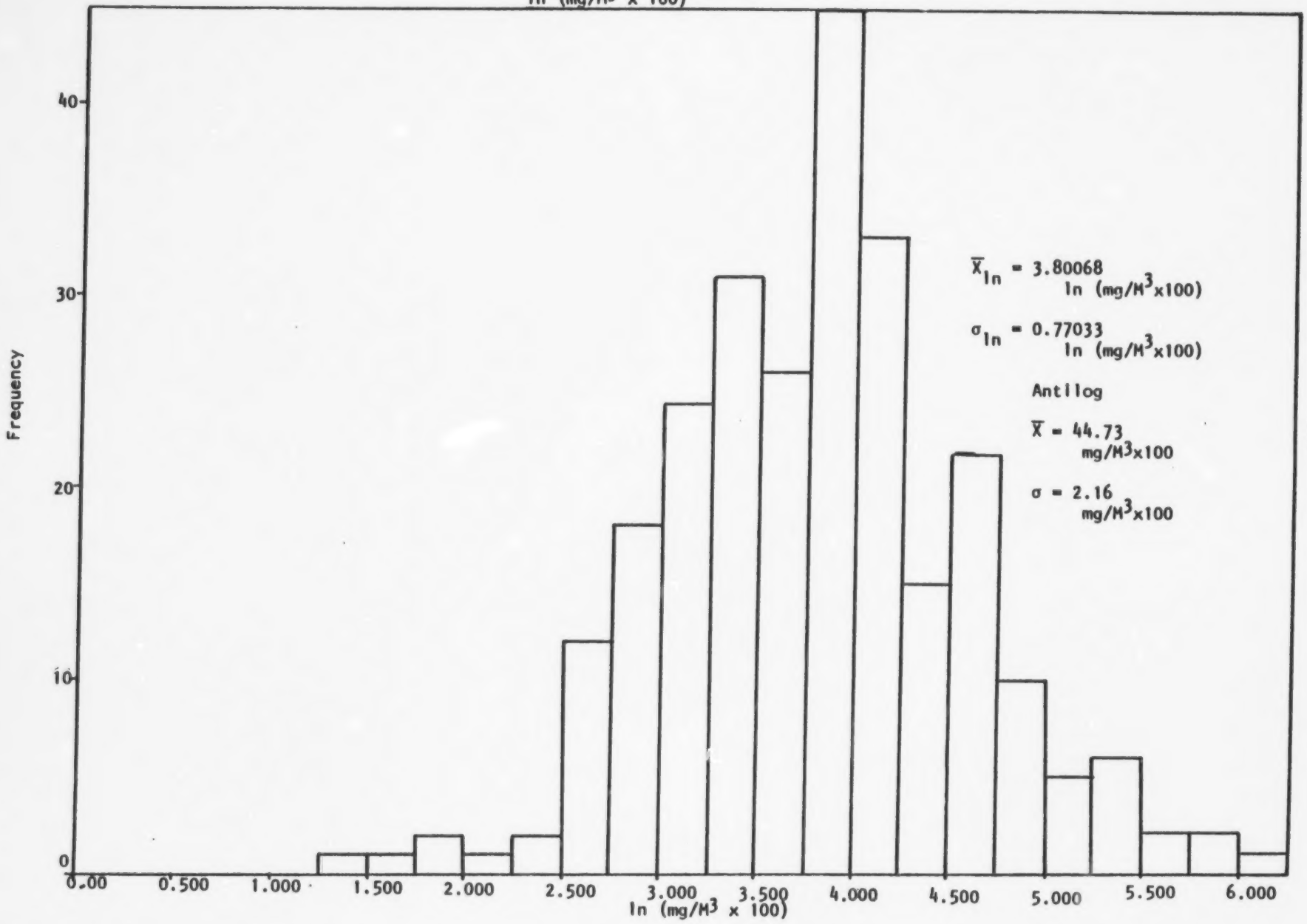


Table - B 11

Gravimetric Dust Sampling

Series - 3 Data

Respirable Dust

$mg/M^3 \times 100$

Class Interval $mg/M^3 \times 100$	f	d	fd	fd^2	f%
0 - 5	2	-4	-8	32	0.80
5 - 10	4	-3	-12	36	1.61
10 - 15	9	-2	-18	36	3.61
15 - 20	18	-1	-18	18	7.23
20 - 25	24	0	-56	-	9.64
25 - 30	17	1	17	17	6.83
30 - 35	21	2	42	84	8.43
35 - 40	17	3	51	153	6.83
40 - 45	11	4	44	176	4.42
45 - 50	24	5	120	600	9.64
50 - 55	16	6	96	576	6.43
55 - 60	14	7	98	686	5.62
60 - 65	14	8	112	896	5.62
65 - 70	6	9	54	486	2.41
70 - 75	6	10	60	600	2.41
75 - 80	2	11	22	242	0.80
80 - 85	1	12	12	144	0.40
85 - 90	4	13	52	676	1.61
90 - 95	3	14	42	588	1.20
95 - 100	9	15	135	2025	3.61
100 - 105	7	16	112	1792	2.81
105 - 110	1	17	17	289	0.40
110 - 115	2	18	36	648	0.80
115 - 120	1	19	19	361	0.40
120 - 125	1	20	20	400	0.40
125 - 130	2	21	42	882	0.80

$\overline{X^1} = 22.5$ $\quad i = 5.0$

Series - 3 Data

	f	d	fd	fd^2	f%
130 - 135	2	22	44	968	0.80
135 - 140	0	23	0	-	-
140 - 145	2	24	48	1152	0.80
145 - 150	1	25	25	625	0.40
150 - 155	0	26	0	0	-
155 - 160	3	27	81	2187	1.20
160 - 165	1	28	28	784	0.40
165 - 170	1	29	29	841	0.40
170 - 175	0	30	0	0	-
175 - 180	0	31	0	0	-
180 - 185	0	32	0	0	-
185 - 190	0	33	0	0	-
190 - 195	1	34	34	1156	0.40
195 - 200	2	35	70	2450	0.80
	$\Sigma f = 249$		1562		99.96

Outlying Observations:

202, 204, 212, 248, 272, 292, 364, 424.

$\Sigma fd = 1506$

$\Sigma fd^2 = 22606$

Series - 3 Data

$N = \varepsilon f = 249$

$\frac{\varepsilon fd}{N} = \frac{1506}{249} = 6.06481$

$\frac{\varepsilon fd^2}{N} = \frac{22606}{249} = 90.787148$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 36.58064$

$\overline{X}^1 = 22.5 \qquad i = 5.0$

$\left(\frac{\varepsilon fd}{N}\right) i = 6.06481 \times 5$

$= 30.32405$

$\overline{X} = \overline{X}^1 + \left(\frac{\varepsilon fd}{N}\right) i$

$= 22.5 + 30.32405$

$= 52.82$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 90.78715 - 36.58064$

$= 54.20651$

$\sigma^1 = 7.3625$

$\sigma = \sigma^1 \times i$

$= 36.81$

$\overline{X} = 52.8$ mg/M^{3}x100 $\qquad \sigma = 36.8$ mg/M^{3}x100

Coefficient of Variation - CV

$CV = \frac{36.8}{52.8} \times 100 = 69.7\%$

Figure - B 6
Gravimetric Dust Sampling
Respirable Dust
Series - 3 Data

$mg/M^3 \times 100$

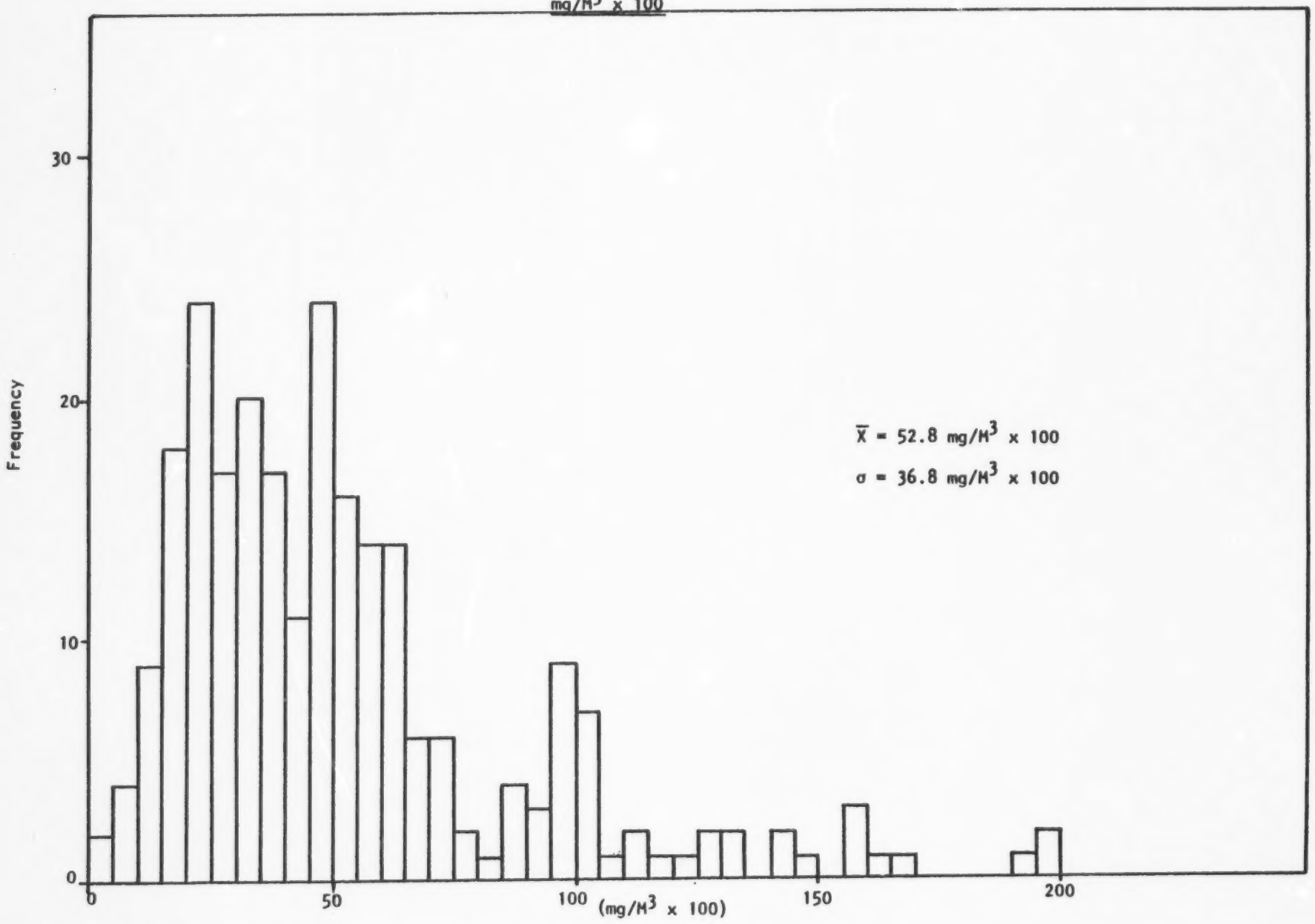


Table - B 12

Gravimetric Dust Sampling Calculation, Using Lognormal Theory, of m, a Statistic to Estimate the Mean u and V^2, a Statistic to Estimate S_u^2. Series - 4 Data

Respirable Dust, ln (mg/M^3 x 100)

Calculation of m		Calculation of V^2	
Notation	Value	Notation	Value
$\bar{u}$	3.76089	$\bar{u}$	0.75667
S_u^2	0.572544	S_u^2	0.5725495
$e^{\bar{u}}$	42.948	$2\bar{u}$	1.51334
N	333	$e^{2\bar{u}}$	4.5267
$T = \frac{1}{2} S_u^2$	0.286275	$\phi n(S_u^2)$	1.3361
$\psi(\frac{1}{2} S_u^2)$	1.335	V^2	4.5267x1.3361
$m =$	57.336	V^2	6.048124
$(e^{\bar{u}})\ \psi n(\frac{1}{2} S_u^2)$		V	2.459 mg/M^3x100
$m =$	57.3 mg/M^3x100		0.025 mg/M^3
	0.057 mg/M^3		

Table - B 13

Gravimetric Dust Sampling

Series - 4 Data

1980

Respirable Dust

In (mg/M^3 x 100)

Class Interval	f	d	fd	fd^2
0.000 - 0.250	0	-15	0	0
0.250 - 0.500	0	-14	0	0
0.500 - 0.750	1	-13	-13	169
0.750 - 1.000	0	-12	0	0
1.000 - 1.250	0	-11	0	0
1.250 - 1.500	2	-10	-20	200
1.500 - 1.750	1	-9	-9	81
1.750 - 2.000	3	-8	-24	192
2.000 - 2.250	5	-7	-35	245
2.250 - 2.500	4	-6	-24	144
2.500 - 2.750	4	-5	-20	100
2.750 - 3.000	16	-4	-64	256
3.000 - 3.250	27	-3	-81	243
3.250 - 3.500	48	-2	-96	192
3.500 - 3.750	57	-1	-57	57
3.750 - 4.000	60	0	-443	
4.000 - 4.250	38	1	38	38
4.250 - 4.500	19	2	38	76
4.500 - 4.750	20	3	60	180
4.750 - 5.000	14	4	56	224
5.000 - 5.250	2	5	10	50
5.250 - 5.500	3	6	18	108
5.500 - 5.750	3	7	21	147
5.750 - 6.000	4	8	32	256
6.000 - 6.250	2	9	18	162
6.250 - 6.500	0	10	0	0
	$\varepsilon f = 333$		291	

$\varepsilon fd = 152$

$\varepsilon fd^2 = 3120$

Series - 4 Data

$N = \varepsilon f = 333$

$\frac{\varepsilon fd}{N} = -\frac{152}{333} = -0.456456456$

$\frac{\varepsilon fd^2}{N} = \frac{3120}{333} = 0.369369369$

$\frac{(\varepsilon fd)^2}{N} = 0.2083525$

$\overline{X}^1_{ln} = 4.125$

$\frac{\varepsilon fd}{N}(i) = -0.4564565\ (0.250)$
$= -0.114114114$

$\overline{X}_{ln} = \overline{X}^1 + \frac{\varepsilon fd}{N}(i)$

$= 3.875 - 0.11411$

$= 3.76089$

$(\sigma^1_{ln})^2 = \frac{\varepsilon fd^2}{N} - \frac{(\varepsilon fd)^2}{N}$

$= 9.369369 - 0.208353$

$= 9.161016$

$\sigma^1_{ln} = 3.0267170$

$\sigma ln = \sigma^1 \times i$

$= 3.02\ 717 \times 0.250$
$= 0.7567925$

$\overline{X}_{ln} = 3.76089$ ln (mg/M^{3}x100)

$\sigma_{ln} = 0.7568$ ln (mg/M^{3}x100)

Antilogarithms

$\overline{X} = 42.98$ mg/M^{3}x100

$= 0.043$ mg/M^3

$\sigma = 2.131428$ mg/M^{3}x100

$= 0.021$ mg/M^3

Figure - B 7

Gravimetric Dust Sampling Series - 4 Data - 1980

Respirable Dust

ln (mg/M^3 x 100)

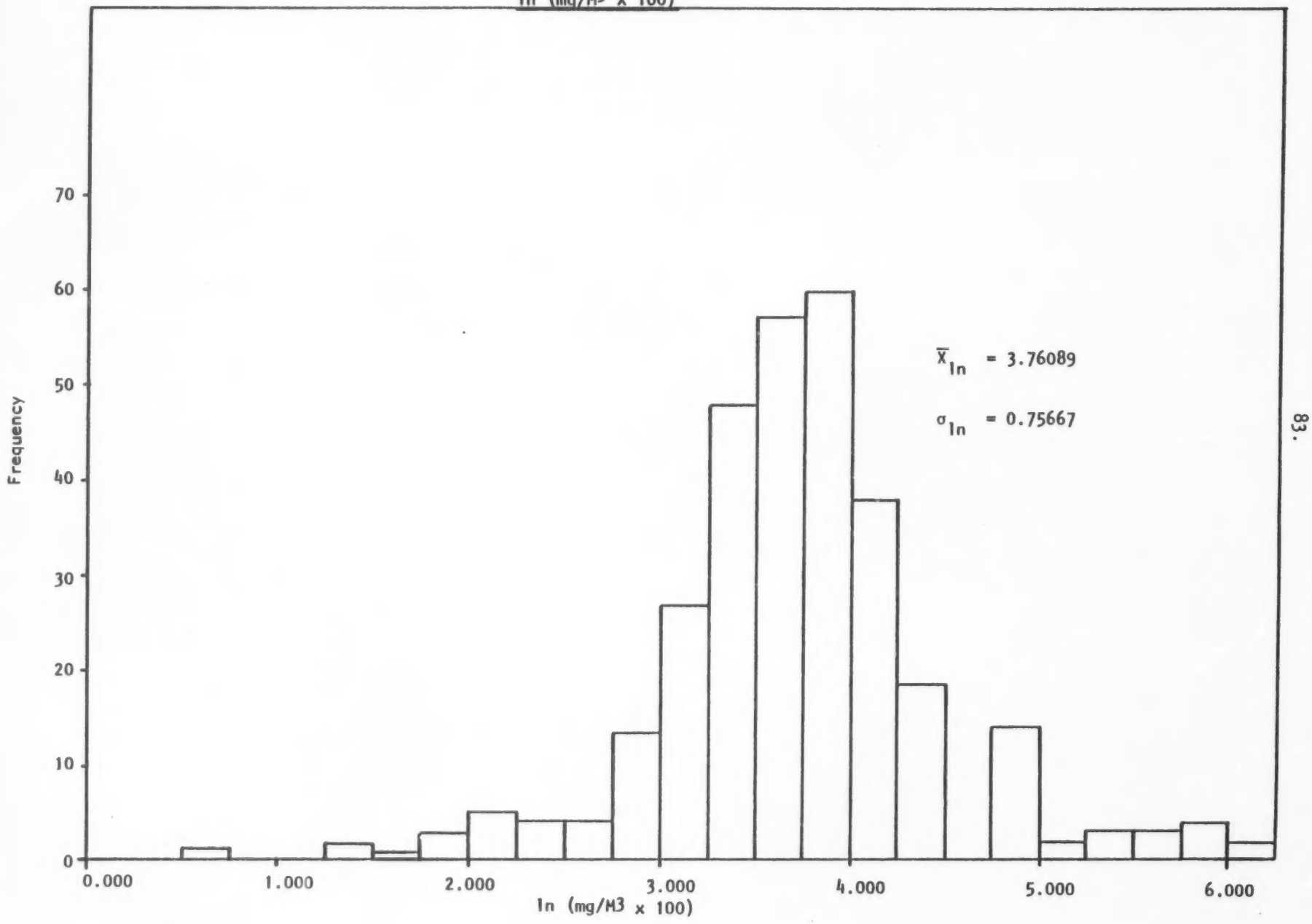


Table B 14

Gravimetric Dust Sampling

Series - 4 Data 1980

Respirable Dust

Underground Gravimetric Dust Sampling

$mg/M^3 \times 100$

Class Interval $mg/M^3 \times 100$	f	d	fd	fd^2
0 - 5	3	-7	-21	147
5 - 10	9	-6	-54	234
10 - 15	5	-5	-25	125
15 - 20	8	-4	-32	128
20 - 25	23	-3	-69	207
25 - 30	24	-2	-48	96
30 - 35	33	-1	-33	33
35 - 40	25	0	-282	
40 - 45	24	1	24	24
45 - 50	24	2	48	96
50 - 55	31	3	93	279
55 - 60	19	4	76	304
60 - 65	8	5	40	200
65 - 70	10	6	60	360
70 - 75	4	7	28	196
75 - 80	10	8	80	640
80 - 85	5	9	45	405
85 - 90	2	10	20	200
90 - 95	4	11	44	484
95 - 100	4	12	48	576
100 - 105	5	13	65	845
105 - 110	3	14	42	588
110 - 115	0	15	0	0
115 - 120	6	16	96	1536
120 - 125	1	17	17	289

Series - 4 Data

	f	d	fd	fd^2
125 - 130	2	18	36	648
130 - 135	3	19	57	1083
135 - 140	1	20	20	200
140 - 145	1	21	21	441
145 - 150	1	22	22	484
150 - 155	1	23	23	529
155 - 160	0	24	0	0
160 - 165	0	25	0	0
165 - 170	0	26	0	0
170 - 175	1	27	27	729
175 - 180	0	28	0	0
180 - 185	0	29	0	0
185 - 190	0	30	0	0
190 - 195	0	31	0	0
195 - 200	1	32	32	1024
			1064	

$\varepsilon f = 301$

$\varepsilon fd = 782$

$\varepsilon fd^2 = 13420$

$i = 5.0$

Series - 4 Data

$N = \varepsilon f = 301$

$\frac{\varepsilon fd}{N} = \frac{782}{301} = 2.59801$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 6.74964$

$\frac{\varepsilon fd^2}{n} = \frac{13420}{301} = 44.58472$

$\bar{X}1 = 37.5 \qquad \frac{\varepsilon fd}{N}(i) = 12.99005$

$\bar{X} = \bar{X}1 + \frac{\varepsilon fd}{N}(i)$

$= 37.5 + 12.99005$

$= 50.49005$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 44.58472 - 6.74964$

$= 37.83508$

$\sigma^1 = 6.15102$

$\sigma = \sigma^1 \times i = 6.1502 \times 5 = 30.75511$

$\bar{X} = 50.5 \text{ mg/M}^3\text{x100} \qquad \sigma = 30.8 \text{ mg/M}^3\text{x100}$

$\bar{X} = 0.51 \text{ mg/M}^3 \qquad \sigma = 0.31 \text{ mg/M}^3$

Figure - B 8

Gravimetric Dust Sampling Series - 4 Data - 1980

Respirable Dust

$mg/M^3 \times 100$

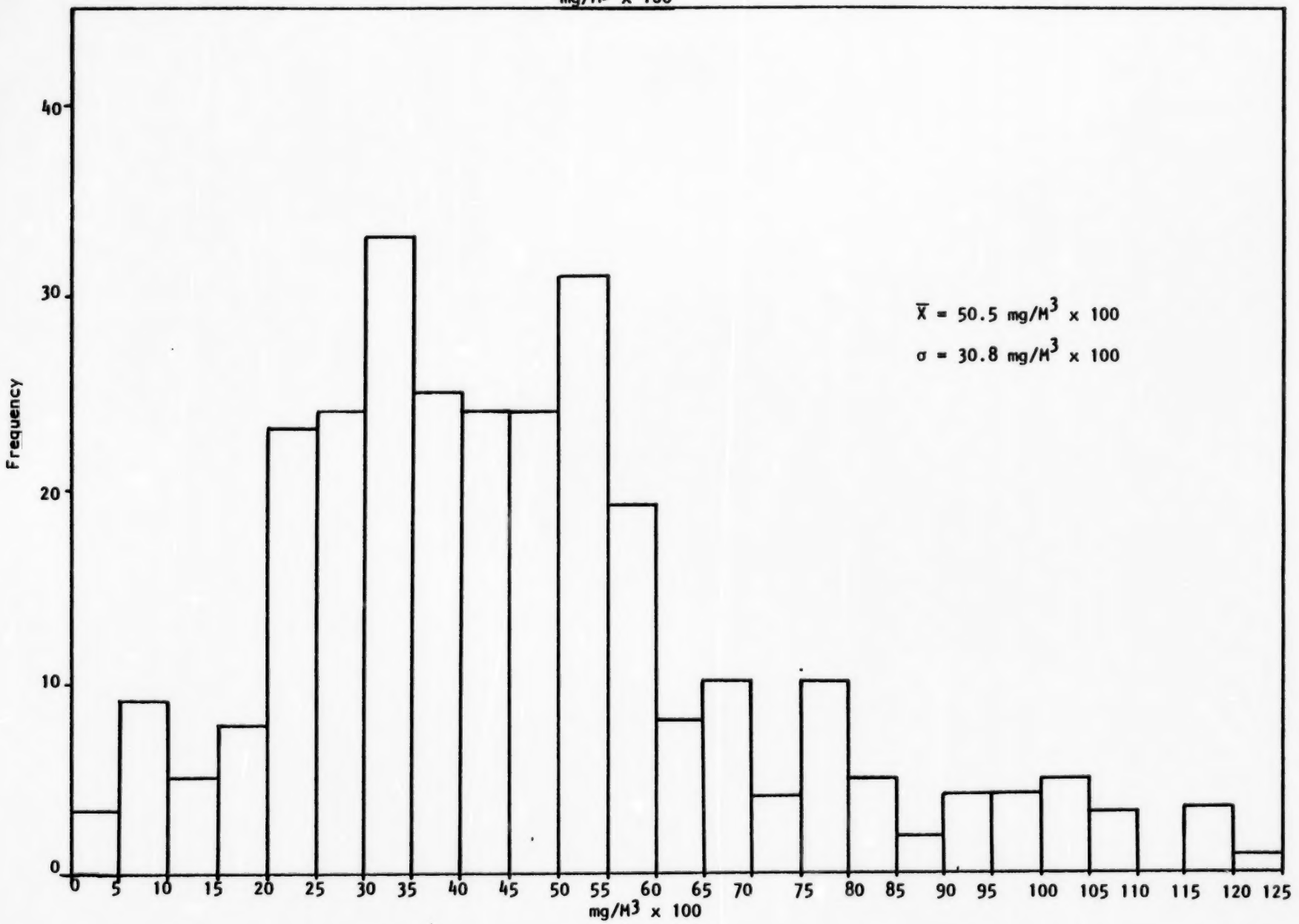


Table - B 15

Gravimetric Dust Sampling

Series - 4 Data

1980

Respirable Dust

Surface Gravimetric Dust Sampling

$mg/M^3 \times 100$

Class Interval $mg/M^3 \times 100$	f	d	fd	fd^2
0 - 5	2	-3	-6	18
5 - 10	6	-2	-12	24
10 - 15	10	-1	-10	10
15 - 20	15	0	-28	
20 - 25	12	1	12	12
25 - 30	9	2	18	36
30 - 35	5	3	15	30
35 - 40	1	4	4	16
40 - 45	1	5	5	25
45 - 50	0	6	0	0
50 - 55	0	7	0	0
55 - 60	1	8	8	64
60 - 65	0	9	0	0
65 - 70	1	10	10	100
70 - 75	1	11	11	121
75 - 80	0	12	0	0
80 - 85	0	13	0	0
85 - 90	0	14	0	0
90 - 95	0	15	0	0
95 - 100	1	16	16	256
100 - 105	1	17	17	289
105 - 110	0	18	0	0
110 - 115	1	19	19	361
115 - 120	0	20	0	0
120 - 125	0	21	0	0
125 - 130	0	22	0	0
130 - 135	0	23	0	0
135 - 140	0	24	0	0
140 - 145	1	25	25	625
	$\varepsilon f = 68$		160	
			$\varepsilon fd = 132$	$\varepsilon fd^2 = 1987$

Series - 4 Data

$N = \varepsilon f = 61$

$\frac{\varepsilon fd^2}{N} = \frac{132}{68} = 1.941176$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 3.768164$

$\frac{\varepsilon fd}{N} = \frac{1987}{68} = 29.22058$

$\bar{X}^1 = 17.5 \qquad \frac{\varepsilon fd}{N}(i) = 1.941176 \times 5$

$\bar{X} = \bar{X} + \frac{\varepsilon fd}{N}(i)$

$= 17.5 + 9.765875 = 27.205875$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 29.22058 - 3.768164$

25.452416

$\sigma^1 = 5.045038$

$\sigma = \sigma^1 \times 5 = 5.045038 \times 5$

$= 25.22519$

$\bar{X} = 27.21 \text{ mg/M}^3 \times 100$

$= 0.27 \text{ mg/M}^3$

$\sigma = 25.23 \text{ mg/M}^3 \times 100$

$= 0.25 \text{ mg/M}^3$

Series - 4 Data

Omitting unusual occurrences
greater than 0.5 mg/M3.

$\varepsilon f = 61$

$\varepsilon fd = 54$

$\varepsilon fd = 171$

$\frac{\varepsilon fd}{N} = \frac{54}{61} = 0.88525$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 0.78367$

$\frac{\varepsilon fd^2}{N} = \frac{171}{61} = 2.80328$

$\bar{X}^1 = 17.5$ $\qquad \frac{\varepsilon fd}{N}(i) = 0.88525 \times 5$

$= 4.42625$

$\bar{X} = \bar{X}^1 + \frac{\varepsilon fd}{N}(i)$

$= 17.5 + 4.42625$

$= 21.92625$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 2.80328 - 0.78367$

$= 2.01961$

$\sigma^1 = 1.42113$

$\sigma = \sigma^1 \times 5 = 7.10565$

$\bar{X} = 21.9$ $\qquad \sigma = 7.11$

Coefficient of Variation = CV = $\frac{7.11}{21.9} \times 100$

$= 0.32\%$

Note: Not included 10.97 mg/M^3 and 4.52 mg/M^3
Lime bin, very dusty areas.

Figure - B 9

Gravimetric Dust Sampling - Series - 4 Data - 1980

Respirable Dust

Surface Samples

$mg/M^3 \times 100$

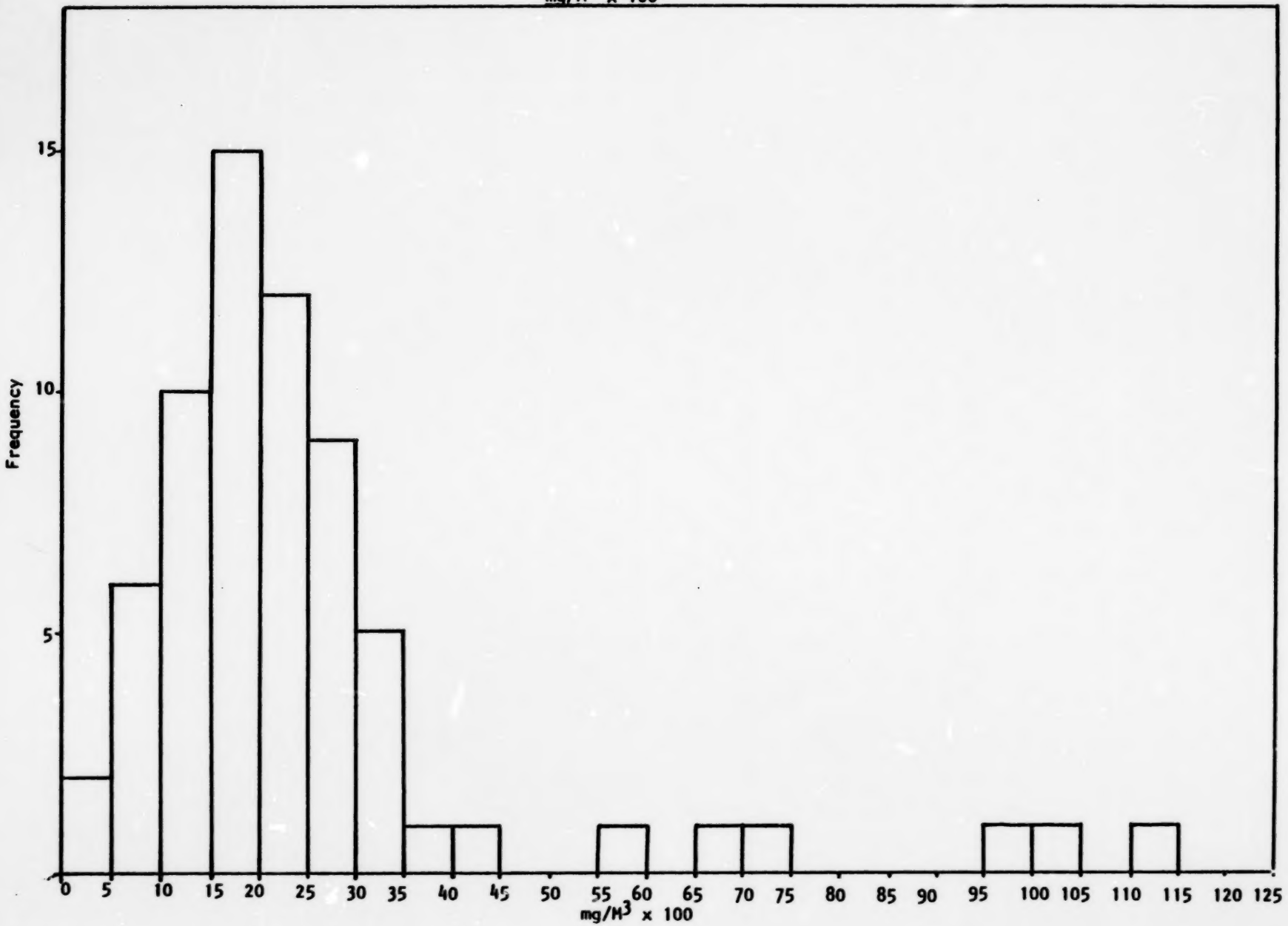


Table - B 16

Gravimetric Dust Sampling

Series - 4 Data

1980

Respirable Dust (1)

mg/M^3

Observation	Location - Occupation
1.04	Drilling
1.07	Scooptram Operator
1.09	Rockbolting
1.11	Fresh air vent plugged
1.15	Diamond Driller
1.16	Cleaning Faces, Scooptran Operator
1.17	Mucking
1.17	Jumbo Operator
1.22	Cleaning Faces, Scooptran Operator (3)
1.25	Drilling
1.38	Spraying Shotcrete
1.39	Rockbolting
1.41	Bolting
1.42	Jumbo Operator Drilling
1.44	Manditory respirator work station (2)
1.77	Rockbolting
1.90	Drilling
2.19	Stope Instructor
2.23	Miner School Stope
2.88	Drilling
3.18	Rockbolting
3.75	Loading Shotcrete
3.92	Welder
3.97	Jackleg drilling
4.10	Rockbolting
5.11	Pipefitting
10.97	Limebin

(1) Observations greater than 1.00 mg/M^3

(2) Respirable Quartz 0.66 mg/M^3

(3) Respirable Quartz 0.32 mg/M^3

Appendix - C

Applied Statistical Analysis

of

Konimeter Observations

Table - C 1

Dust Sampling - 1977

KONIMETER

Particles per Cubic Centimeter

p.p.c.c.

Series - 1 Data

Class Interval	f	d	fd	fd^2
0 - 100	202	0	-	-
100 - 200	93	1	93	93
200 - 300	51	2	102	204
300 - 400	35	3	105	315
400 - 500	29	4	116	464
500 - 600	9	5	45	225
600 - 700	8	6	48	288
700 - 800	4	7	28	196
800 - 900	3	8	24	192
900 - 1000	2	9	18	162
1000 - 1100	2	10	20	200

$\varepsilon f = \overline{438}$

$\varepsilon fd = \overline{599}$

$\varepsilon fd^2 = \overline{2339}$

$i = 100$

$\overline{X}^1 = 50$ p.p.c.c.

$N = \varepsilon f = 438$

$\frac{\varepsilon fd}{N} = \frac{599}{438} = 1.3675799$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 1.8702748$

$\frac{\varepsilon fd^2}{N} = \frac{2339}{438} = 5.3401826$

$\overline{X}^1 = 50.0$

$\frac{\varepsilon fd}{N}(i) = 136.75799$

$\overline{X} = \overline{X}^1 + \frac{\varepsilon fd}{N}(i) = 50 + 136.75799$
$= 186.75799$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 5.34018 - 1.87027$

$= 3.46991$

$\sigma^1 = 1.862767$

$\sigma = \sigma^1 \times i \qquad i = 100$

$= 186.2726$

$\overline{X} = 186.76$ p.p.c.c. $\qquad \sigma = 186.27$ p.p.c.c.

Coefficient of Variation (V)

$V = \frac{\sigma}{\overline{X}} \times 100$

$= \frac{186.27}{186.76} \times 100 = 99.74\%$

Figure - C 1
Dust Sampling - 1977
KONIMETER
p.p.c.c.
Series - 1 Data

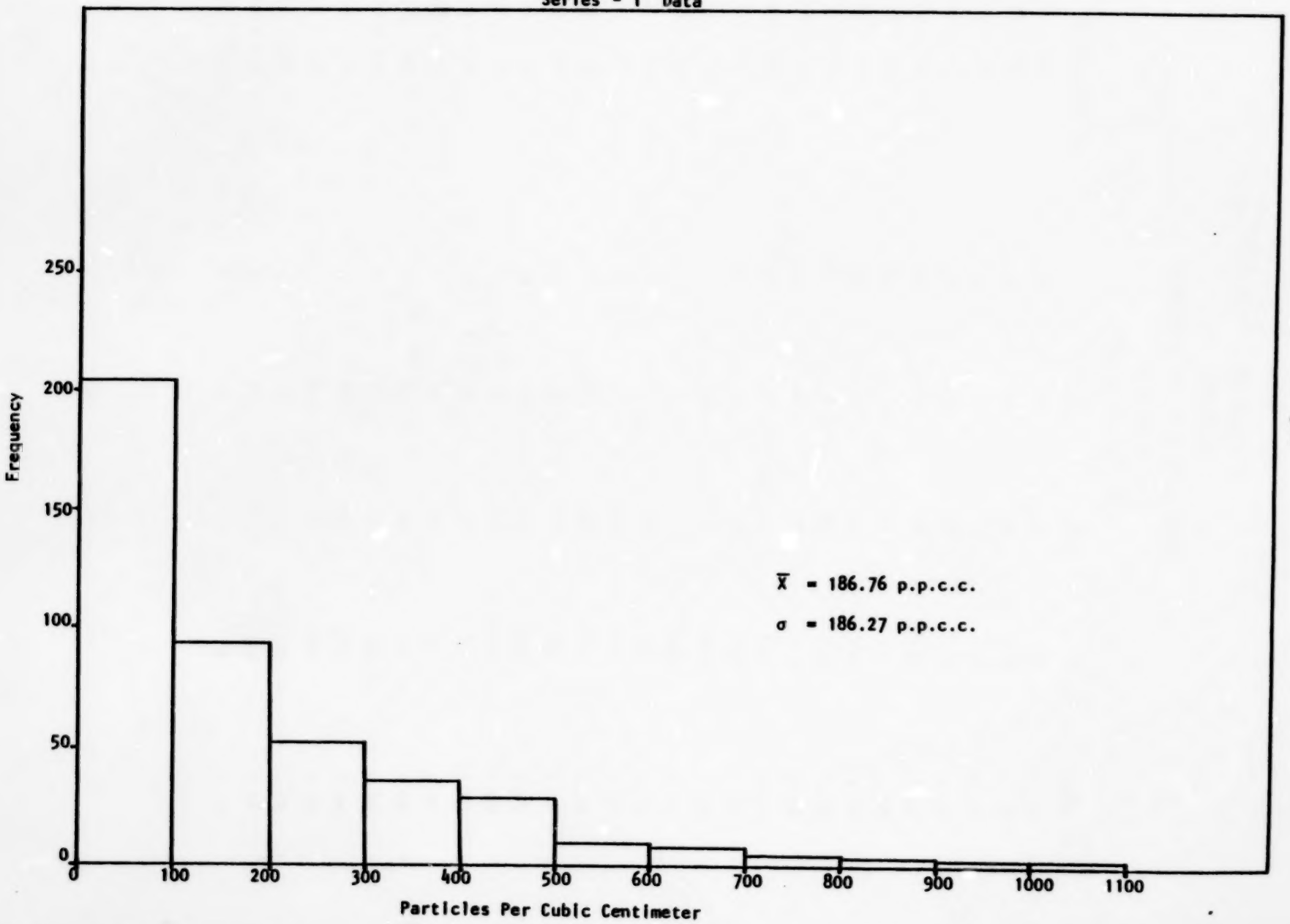


Table - C 2

Dust Sampling

KONIMETER

Particles Per Cubic Centimeter

(p.p.c.c.)

Series - 1 Data

Class Interval	f	d	fd	fd^2	f%
0 - 25	0	-2	0	0	0
25 - 50	0	-1	0	0	0
50 - 75	149	0	0	0	34.02
75 - 100	53	1	53	53	12.10
100 - 125	33	2	66	132	7.53
125 - 150	24	3	48	144	5.48
150 - 175	15	4	60	240	3.42
175 - 200	21	5	105	525	4.79
200 - 225	17	6	102	612	3.88
225 - 250	14	7	98	686	3.20
250 - 275	12	8	96	768	2.74
275 - 300	8	9	72	648	1.83
300 - 325	11	10	110	1100	2.51
325 - 350	5	11	55	605	1.14
350 - 375	9	12	108	1296	2.05
375 - 400	10	13	130	1690	2.28
400 - 425	10	14	140	1960	2.28
425 - 450	9	15	135	2025	2.05
450 - 475	7	16	112	1792	1.60
475 - 500	3	17	51	867	0.68
500 - 525	2	18	36	648	0.46
525 - 550	2	19	38	722	0.46
550 - 575	2	20	40	800	0.46
575 - 600	3	21	63	1323	0.68
600 - 625	1	22	22	484	0.23
625 - 650	4	23	92	2116	0.91
650 - 675	3	24	72	1728	0.68
675 - 700	0	25	0	0	0

Series - 1 Data

700 - 725	3	26	78	2028	0.68
725 - 750	0	27	0	0	0
750 - 775	0	28	0	0	0
775 - 800	1	29	29	841	0.23
800 - 825	2	30	60	1800	0.46
825 - 850	1	31	31	961	0.23
850 - 875	0	32	0	0	0
875 - 900	0	33	0	0	0
900 - 925	1	34	34	1156	0.23
925 - 950	1	35	35	1225	0.23
950 - 975	0	36	0	0	0
975 - 1000	0	37	0	0	0
1000 - 1025	0	38	0	0	0
1025 - 1050	0	39	0	0	0
1050 - 1075	0	40	0	0	0
1075 - 1100	2	41	82	3362	0.46
	$\varepsilon f = 438$				99.99

$$\varepsilon fd = 2253$$

$$\varepsilon fd^2 = 34337$$

$$i = 25$$

$$\bar{X}^1 = 62.5$$

Series - 1 Data

$N = \varepsilon f = 438$

$\frac{\varepsilon fd}{N} = \frac{2253}{438} = 5.14384$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 26.459067$

$\frac{\varepsilon fd^2}{N} = \frac{34337}{438} = 78.39498$

$\overline{X^1} = 62.5 \qquad i = 25$

$\frac{\varepsilon fd}{N}(i) = 128.596$

$\overline{X} = \overline{X^1} + \frac{\varepsilon fd}{N}(i)$

$= 62.5 + 128.596$

$= 191.096$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 78.39498 - 26.459067$

$= 51.9359$

$\sigma^1 = 7.2066$

$\sigma = \sigma^1 \times i$

$= 7.2066 \times 25$

$= 180.17$

$\overline{X} = 191.1$ p.p.c.c. $\qquad \sigma = 180.2$ p.p.c.c.

Coefficient of Variation (V)

$V = \frac{\sigma}{\overline{X}} \times 100 = \frac{180.2}{191.1} \times 100 = 94.3\%$

Figure - C 2

Konimeter Dust Sampling Distribution

Series - 1 Data

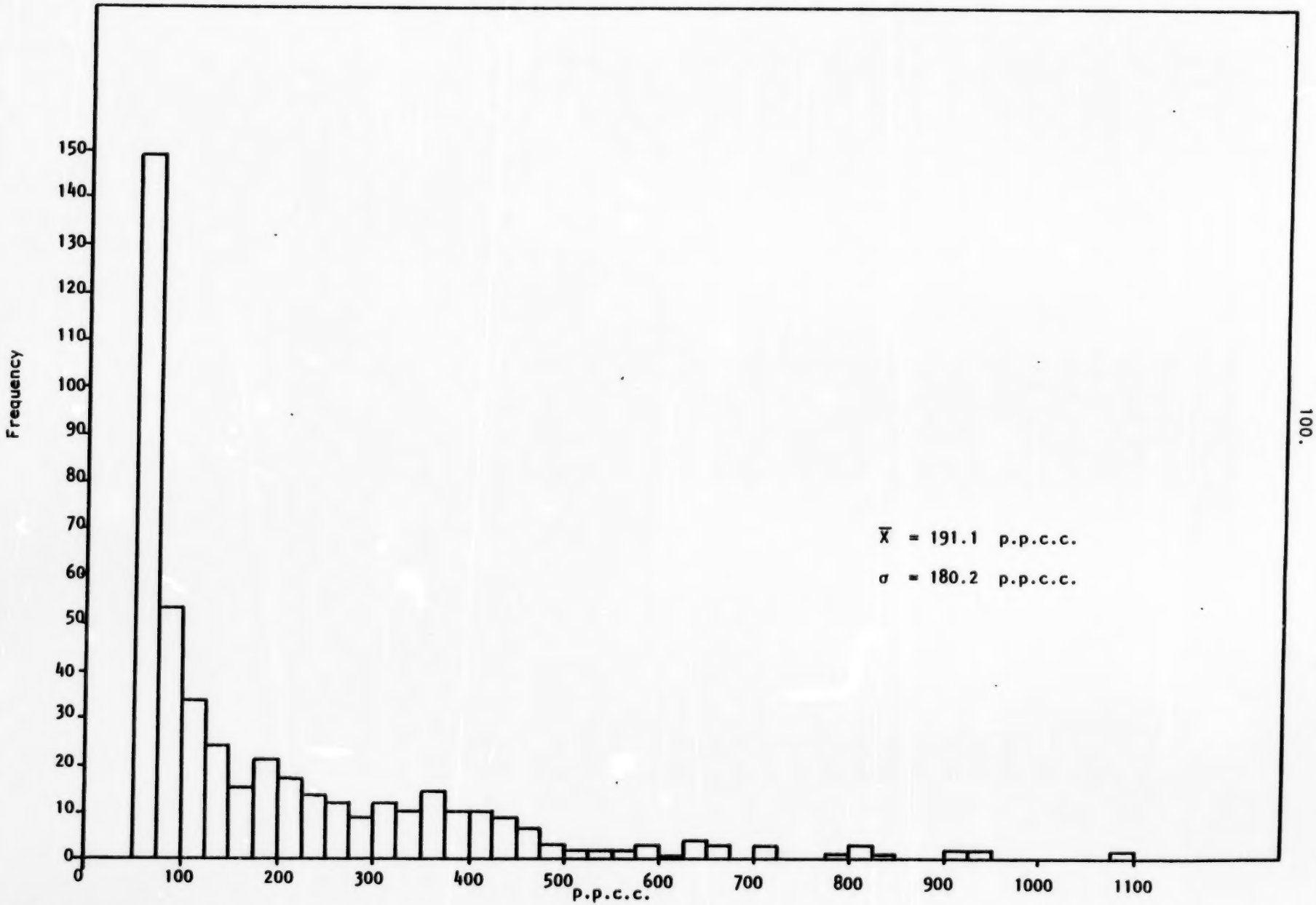


Table - C 3

Dust Sampling Konimeter

Particles Per Cubic Centimeter

p.p.c.c.

Series - 3 Data

Class Interval	f	d	fd	fd^2	f%
0 - 50	1	-1	-1	1	0.41
50 - 100	47	0	0	-	19.42
100 - 150	27	1	27	27	11.16
150 - 200	29	2	58	116	11.98
200 - 250	16	3	48	144	6.61
250 - 300	20	4	80	320	8.26
300 - 350	20	5	100	500	8.26
350 - 400	24	6	144	864	9.92
400 - 450	11	7	77	539	4.54
450 - 500	9	8	72	576	3.72
500 - 550	10	9	90	810	4.13
550 - 600	13	10	130	1300	5.37
600 - 650	5	11	55	605	2.07
650 - 700	5	12	60	720	2.07
700 - 750	0	13	0	0	0
750 - 800	3	14	42	588	1.23
800 - 850	0	15	0	0	0
850 - 900	0	16	0	0	0
900 - 950	2	17	34	578	0.82
	$\varepsilon f = \overline{242}$		$\varepsilon fd = \overline{1016}$	$\varepsilon fd^2 = \overline{7687}$	$\overline{99.97}$

$\overline{X}^1 = 75$ $\quad i = 50$

Series - 3 Data

$N = \varepsilon f = 242$

$\frac{\varepsilon fd}{N} = \frac{1016}{242} = 4.19835$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 17.62613$

$\frac{\varepsilon fd^2}{N} = \frac{7687}{242} - 31.76446$

$\overline{X}^1 = 75 \qquad i = 50$

$\frac{\varepsilon fd}{N}(i) = 209.9175$

$\overline{X} = \overline{X}^1 + \frac{\varepsilon fd}{N}(i)$

$= 75 + 209.9175$

$= 284.9175$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 31.76446 - 17.62613$

$= 14.13833$

$\sigma^1 = 3.7600$

$\sigma = \sigma^1 \times i$

$= 188.00$

$\overline{X} = 284.9$ p.p.c.c. $\qquad \sigma = 188.0$ p.p.c.c.

Coefficient of Variation (V)

$V = \frac{\sigma}{\overline{X}} \times 100 = 188 \times 100 = 66.2\%$

Figure - C 3

Konimeter Dust Sampling Distribution
Series - 3 Data
p.p.c.c.

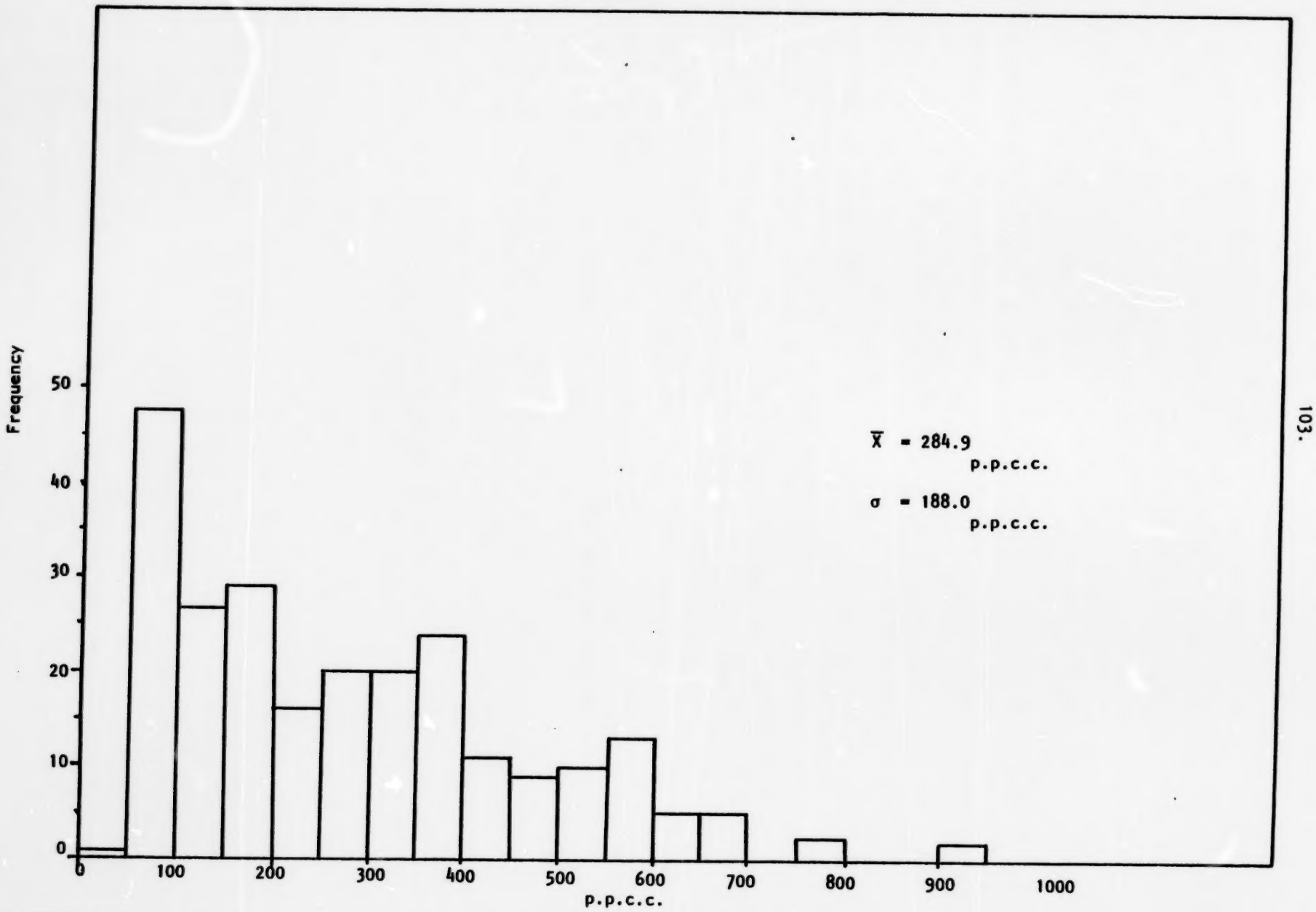


Table - C 4

Dust Sampling Konimeter

Particles Per Cubic Centimeter

p.p.c.c.

Series - 3 Data

Class Interval	f	d	fd	fd^2	f%
0 - 25	1	-2	-2	4	0.41
25 - 50	0	-1	0	0	0
50 - 75	31	0	0	0	12.81
75 - 100	16	1	16	16	6.61
100 - 125	13	2	26	52	5.37
125 - 150	14	3	42	126	5.79
150 - 175	13	4	52	208	5.37
175 - 200	16	5	80	400	6.61
200 - 225	9	6	54	324	3.72
225 - 250	7	7	49	343	2.89
250 - 275	11	8	88	704	4.55
275 - 300	9	9	81	729	3.72
300 - 325	9	10	90	900	3.72
325 - 350	11	11	121	1331	4.55
350 - 375	16	12	192	2304	6.61
375 - 400	8	13	104	1352	3.31
400 - 425	10	14	140	1960	4.13
425 - 450	1	15	15	225	0.41
450 - 475	4	16	64	1024	1.65
475 - 500	5	17	85	1445	2.07
500 - 525	4	18	72	1296	1.65
525 - 550	6	19	114	2166	2.48
550 - 575	8	20	160	3200	3.31
575 - 600	5	21	105	2205	2.07
600 - 625	2	22	44	968	0.83
625 - 650	3	23	69	1587	1.23
650 - 675	2	24	48	1152	0.83
675 - 700	3	25	75	1875	1.23
700 - 725	0	26	0	0	0
725 - 750	0	27	0	0	0
750 - 775	1	28	28	784	0.41
775 - 800	2	29	58	1682	0.83

Series - 3 Data

800 - 825	0	30	0	0	0
825 - 850	0	31	0	0	0
850 - 875	0	32	0	0	0
875 - 900	0	33	0	0	0
900 - 925	0	34	0	0	0
925 - 950	2	35	70	2450	0.83
					100.00

$\varepsilon f = 242$

$\varepsilon fd = 2140$

$\varepsilon fd^2 = 32812$

$\bar{X}^1 = 62.5$ $\quad i = 25.0$

Series - 3 Data

$N = \varepsilon f = 242$

$\frac{\varepsilon fd}{N} = \frac{2140}{242} = 8.842975$

$\left(\frac{\varepsilon fd}{N}\right)^2 = 78.19821$

$\frac{\varepsilon fd^2}{N} = \frac{32812}{242} = 135.58677$

$\bar{X}^1 = 62.5 \qquad i = 25.0$

$\varepsilon fd\,(i) = 221.0743$

$\bar{X} = \bar{X}^1 + \frac{\varepsilon fd}{N}\,(i)$

$= 62.5 + 221.0743$

$= 283.574$

$(\sigma^1)^2 = \frac{\varepsilon fd^2}{N} - \left(\frac{\varepsilon fd}{N}\right)^2$

$= 135.58677 - 78.19821$

$= 57.38856$

$\sigma^1 = 7.57552$

$\sigma = \sigma^1 \times i$

$= 7.57552 \times 25.0$

$= 189.388$

$\bar{X} = 283.6$ p.p.c.c. $\qquad \sigma = 189.4$ p.p.c.c.

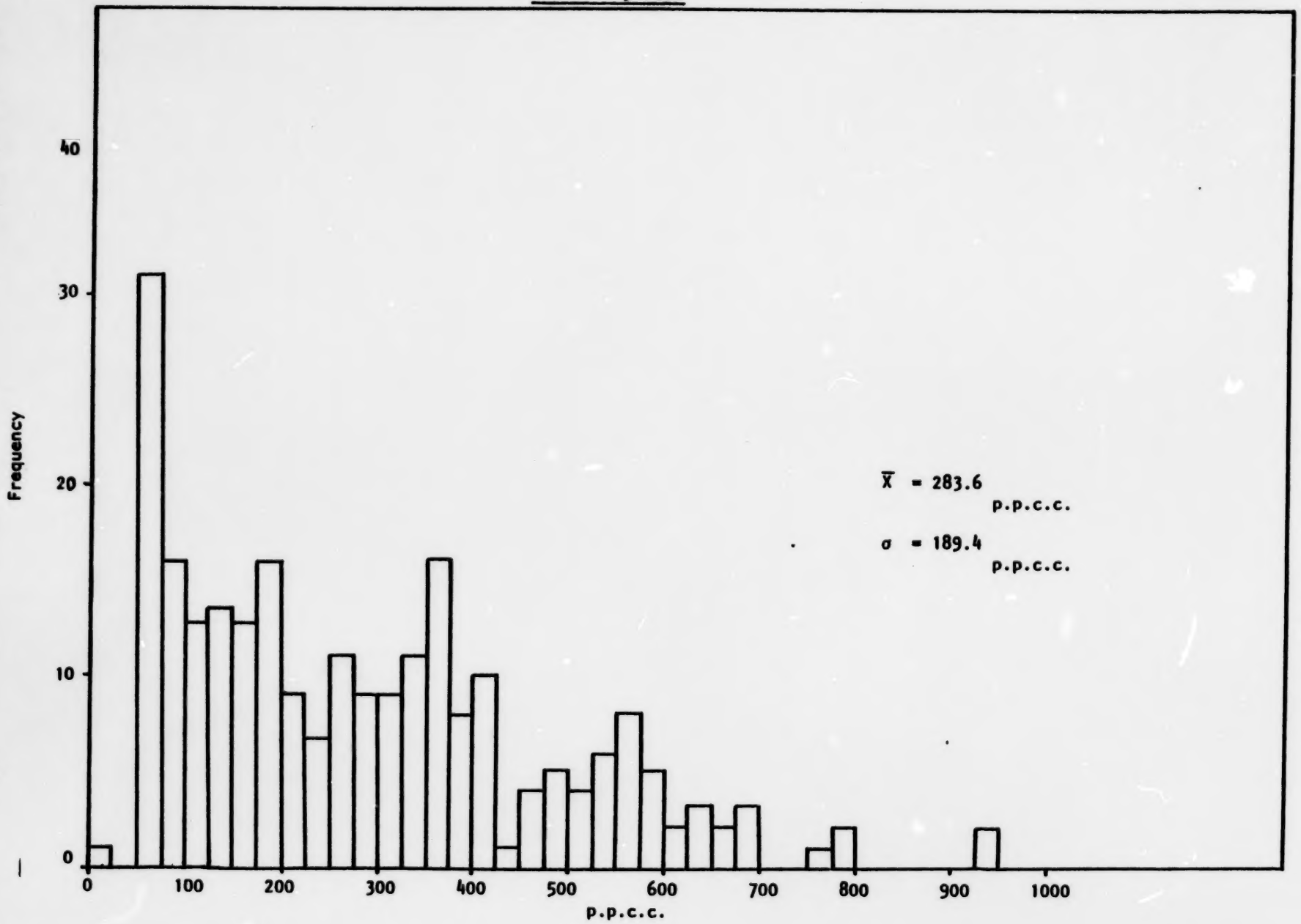
Coefficient of Variation (V)

$V = \frac{\sigma}{\bar{X}} \times 100 = \frac{189.4}{283.6} \times 100 = 66.8\%$

Figure - C 4

Konimeter Dust Sampling Distribution

Series - 3 Data



Appendix - D

Applied Statistical Analysis

of

Respirable Quartz and Dust Observations Using small Number Statistical Methods to Calculate the Confidence Limits for the Mean at the 95% Probability Level

Occupation Data

Occupations

31 - JDT Operator

38 - Scooptram Operator

39 - AN/FO Loader Operator

40 - Mobile Rockbolt Operator

42 - Jumbo Drill Operator

43 - Longhole Driller

47 - Conveyor Belt Operator

59 - Rock Breaker Operator Grizzly

80 - Mine Shift Boss.

Data Identification

A - Total respirable Dust MG/M^3 x 100

B - Respirable Combustible Dust MG/M^3 x 100

C - Respirable Quartz Dust $\mu G/M^3$

Table - D 1

Dust Sampling Observations

JDT Operator

Job No. 31

Location		A	B	C
102		29	-	21
102		38	-	20
102		54	38	31
102		53	46	41
102		28	-	20
104		16	-	10
104		63	52	40
104		51	-	51
104		58	45	35
101		64	24	30
101		41	-	21
102		33	-	20
101		52	39	31
102		49	47	22
N	-	14	7	14
ϵx	-	629	291	393
ϵx^2	-	30955	12595	12595
$\bar{X}$	-	44.5	44.928	28.071
s	-	14.985	14.398	10.965
$S_{\bar{x}} = \frac{s}{\sqrt{n}}$	-	4.005	5.441	2.931
$t_{0.975}$	-	2.16	2.447	2.16
$t\, S_{\bar{x}}$	-	8.65	13.31	6.33
$\bar{X} - t\, S_{\bar{x}}$	-	35.85	31.62	21.74
$\bar{X} + t\, S_{\bar{x}}$	-	53.15	58.24	34.40
		$Mg/M^3 \times 100$	$Mg/M^3 \times 100$	$\mu g/M^3$

Table - D 2

Job No. 38

Scooptram Operator ST-R

Location	A	B	C
102	63	43	51
102	54	37	50
102	101	78	122
102	110	82	113
102	37	-	21
103	97	75	150
103	95	86	81
103	75	60	80
103	128	106	103
104	58	46	30
104	130	114	62
104	54	44	10
104	89	68	67
101	84	67	64
101	87	67	81
101	81	62	101
101	56	35	70
101	73	50	82
105	72	49	41
105	56	-	75
105	64	15	22
105	43	-	12
105	32	-	11
115	68	53	32

Job No. 38

	A	B	C
N	24	20	24
εx_2	1807	1237	1531
εx	151663	87537	130159
$\bar{X}$	75.292	61.85	63.79166
S	26.0525	24.0925	37.5869
$S_{\bar{x}} = \frac{S}{\sqrt{N}}$	5.3179	5.3872	7.67241
$t_{o.975}$	2.068	2.093	2.068
$t\ S_{\bar{x}}$	10.998	11.27551	15.8665
$\bar{X} - t\ S_{\bar{x}}$	64.294	50.57	47.93
$\bar{X} + t\ S_{\bar{x}}$	86.29 $Mg/M^3 \times 100$	73.13 $Mg/M^3 \times 100$	79.66 $\mu g/M^3$

Table - D 3

Job No. 39

AN/FO Loader Operator

Location	A	B	C
102	18	-	20
102	40	16	30
102	45	35	21
102	66	-	24
102	41	29	21
103	88	84	49
103	81	77	40
103	64	56	20
101	37	32	21
104	59	51	20
104	57	49	30
104	48	-	21
104	45	38	20
105	23	-	10
105	56	49	30
105	62	51	20
105	32	-	-
105	78	69	23

Job. No. 39

	A	B	C
N	18	13	17
εx	940	636	420
εx^2	55432	35676	11670
$\bar{X}$	52.222	48.9320	24.70588
S	19.3164	19.49556	8.991417
$S_{\bar{x}} = \frac{S}{\sqrt{N}}$	4.55291	5.40709	2.180742
$t_{0.975}$	2.110	2.179	2.120
$t\, S_{\bar{x}}$	9.60664	11.782047	4.75563
$\bar{X} - t\, S_{\bar{x}}$	42.62	37.14	19.95
$\bar{X} + t\, S_{\bar{x}}$	61.83	60.71	29.46
	$Mg/M^3 \times 100$	$Mg/M^3 \times 100$	$\mu g/M^3$

Table - D 4

Job No. 40

Mobile Rockbolt Operator

Location	A	B	C
102	67	47	20
102	65	44	50
102	47	-	41
102	59	46	20
103	58	53	30
103	87	74	60
103	80	61	41
103	63	49	30
103	105	79	90
104	39	-	10
104	47	-	20
104	30	-	41
104	38	-	50
101	85	42	50
101	81	59	60
101	58	41	40
101	31	-	10
107	25	-	12
107	36	-	14
107	30	-	11
107	30	-	21
107	28	-	12

Job No. 40

	A	B	C
N	21	11	22
εx	1189	595	733
εx^2	75421	33835	33689
$\bar{X}$	54.045	54.090	33.318
S	23.054	12.848	21.007
$S\bar{x} = \frac{s}{\sqrt{N}}$	4.915	3.874	4.478
$t_{o.\,975}$	2.080	2.228	2.080
$t\ S\bar{x}$	10.223	8.631	9.316
$\bar{X} - t\ S\bar{x}$	43.82	45.46	24.00
$\bar{X} + t\ S\bar{x}$	64.27	62.72	42.63
	$Mg/M^3 \times 100$	$Mg/M^3 \times 100$	$\mu g/M^3$

Table - D 5

Job No. 42

Jumbo Drill Operator

Location	A	B	C
102	53	-	41
102	27	-	54
102	52	-	21
102	46	-	21
102	59	-	72
103	90	86	59
103	74	79	20
103	75	60	37
103	80	70	20
103	112	98	41
104	74	63	20
104	49	39	40
104	88	68	80
104	51	36	41
101	48	37	31
101	58	-	20
101	37	-	31
101	28	-	22
101	40	-	22
107	65	51	23
107	30	-	12

Job No. 42

	A	B	C
N	21	11	21
εx	1236	687	728
εx^2	82752	47121	32038
$\bar{X}$	58.857	62.455	34.667
S	22.366	20.530	18.440
$S\bar{x} = \frac{s}{\sqrt{N}}$	4.881	6.189	4.024
$t_{o.\ 975}$	2.086	2.228	2.086
$t\ S\bar{x}$	10.181	13.791	8.394
$\bar{X} - t\ S\bar{x}$	48.68	48.66	26.27
$\bar{X} + t\ S\bar{x}$	69.04	76.25	43.06
	$Mg/M^3 \times 100$	$Mg/M^3 \times 100$	$\mu g/M^3$

Table - D 6

Job No. 43

Longhole Driller

Location	A	B	C
107	89	56	10
107	70	50	22
107	137	75	48
112	17	-	10
112	16	-	10
112	29	-	-
112	22	-	10
112	36	-	10
112	22	-	10
112	33	-	11
N	10	3	9
ϵx	471	181	141
ϵx^2	36329	11261	3509
$\bar{X}$	47.100	60.333	15.667
S	39.644	13.051	12.748
$S\bar{x} = \frac{s}{\sqrt{N}}$	12.537	7.535	4.250
$t_{o.\ 975}$	2.262	4.303	2.306
$t\ S\bar{x}$	28.358	32.423	9.799
$\bar{X} - t\ S\bar{x}$	18.74	27.91	5.87
$\bar{X} + t\ S\bar{x}$	75.46	92.76	25.47
	$Mg/M^3 x100$	$Mg/M^3 x100$	$\mu g/M^3$

Table - D 7

Job Number 47

Conveyor Belt Operator

Location	A	B	C
117	50	-	23
117	214	46	938
117	218	68	660
117	80	56	59
117	178	92	142
117	254	197	72
117	493	101	1686
117	338	43	1590
117	93	51	80
117	69	45	102
117	117	60	107
117	64	46	83
117 *	224	104	249
117 *	224	104	249
N	14	13	14
ϵx_2	2616	1013	6040
ϵx	687260	101173	6874642
$\bar{X}$	186.857	77.923	431.43
S	123.551	43.047	573.04
$S\bar{x} = \frac{s}{\sqrt{N}}$	33.020	11.939	153.15
$t_{o.\ 975}$	2.16	2.179	2.16
$t\ S\bar{x}$	71.324	26.016	330.804
$\bar{X} - t\ S\bar{x}$	115.53	51.91	100.62
$\bar{X} + t\ S\bar{x}$	258.18	103.94	762.23
	$Mg/M^3 x100$	$Mg/M^3 x100$	$\mu g/M^3$

* These are two (2) different observations.

Table - D 8

Job Number 59

Rock Breaker Operator (Grizzly)

Location	A	B	C
103	46	48	10
103	71	63	20
103	64	44	30
103	53	46	30
103	47	-	58
101	87	65	52
101	120	65	145
101	49	20	50
101	75	54	52
101	89	61	71
105	67	43	82
105	92	83	43
105	83	65	51
105	61	-	14
N	14	12	14
ϵx	1004	657	708
ϵx^2	77750	38775	51008
$\bar{X}$	71.714	54.75	50.571
S	21.029	15.967	34.198
$S\bar{x} = \frac{s}{\sqrt{N}}$	5.620	4.609	9.140
$t_{o.\ 975}$	2.16	2.201	2.16
$t\ S\bar{x}$	12.140	10.145	19.742
$\bar{X} - t\ S\bar{x}$	59.57	44.61	30.83
$\bar{X} + t\ S\bar{x}$	83.85	64.89	70.31
	$Mg/M^3 \times 100$	$Mg/M^3 \times 100$	$\mu g/M^3$

Table - D 9

Job Number 80

Mine Shift Boss

Location	A	B	C
102	14	-	20
102	20	-	20
102	35	-	10
102	15	-	-
102	14	-	10
103	32	28	20
103	34	-	30
103	39	-	15
103	45	-	30
103	72	66	36
104	25	-	20
104	21	-	20
104	21	-	20
104	25	16	20
101	44	-	20
101	24	-	20
101	27	-	20
101	24	-	21
101	27	-	31
105	17	-	10
107	27	-	21
107	34	-	11
107	28	-	21
107	33	-	12

Job Number 80

	A	B	C
112	23	-	20
112	25	-	-
112	56	45	13
112	31	-	10
112	34	-	10
117	132	60	279
N	30	5	28
εx	998	215	790
εx^2	47708	11021	88708
$\bar{X}$	33.267	43.0	28.214
S	22.367	21.071	49.625
$S\bar{x} = \frac{s}{\sqrt{N}}$	4.084	9.423	9.378
$t_{o.975}$	2.045	2.776	2.052
$t\ S\bar{x}$	8.351	26.159	19.244
$\bar{X} - t\ S\bar{x}$	24.92	16.84	8.97
$\bar{X} + t\ S\bar{x}$	41.62	69.16	47.46
	$Mg/M^3 \times 100$	$Mg/M^3 \times 100$	$\mu g/M^3$

Figure D-1

Personal Dust Sampling Observations in Uranium Mines

(Respirable Quartz µg/M3)

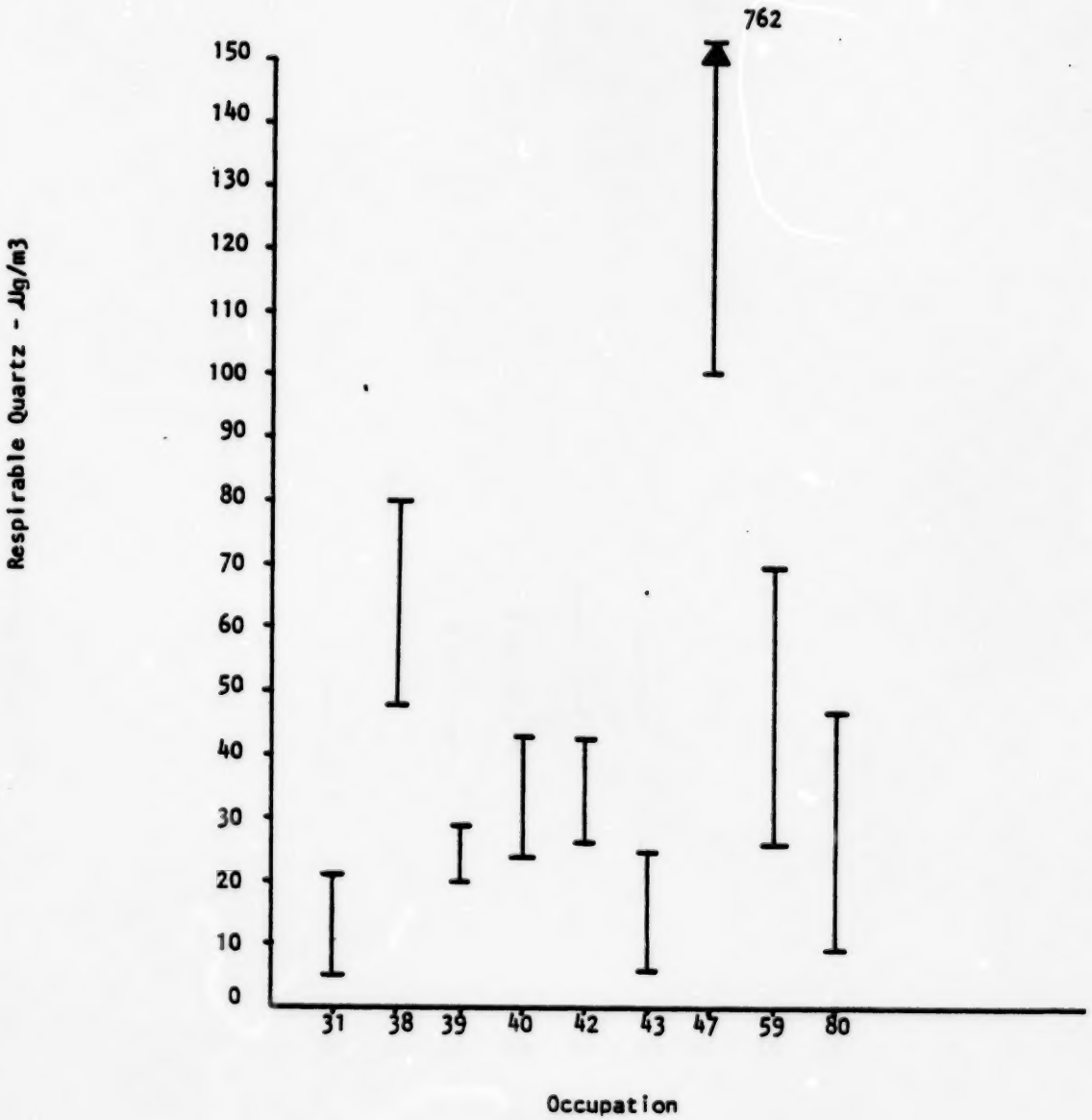


Figure D- 2

Personal Dust Sampling Observations in Uranium Mines

(Total Respirable Dust $mg/m^3 \times 100$)

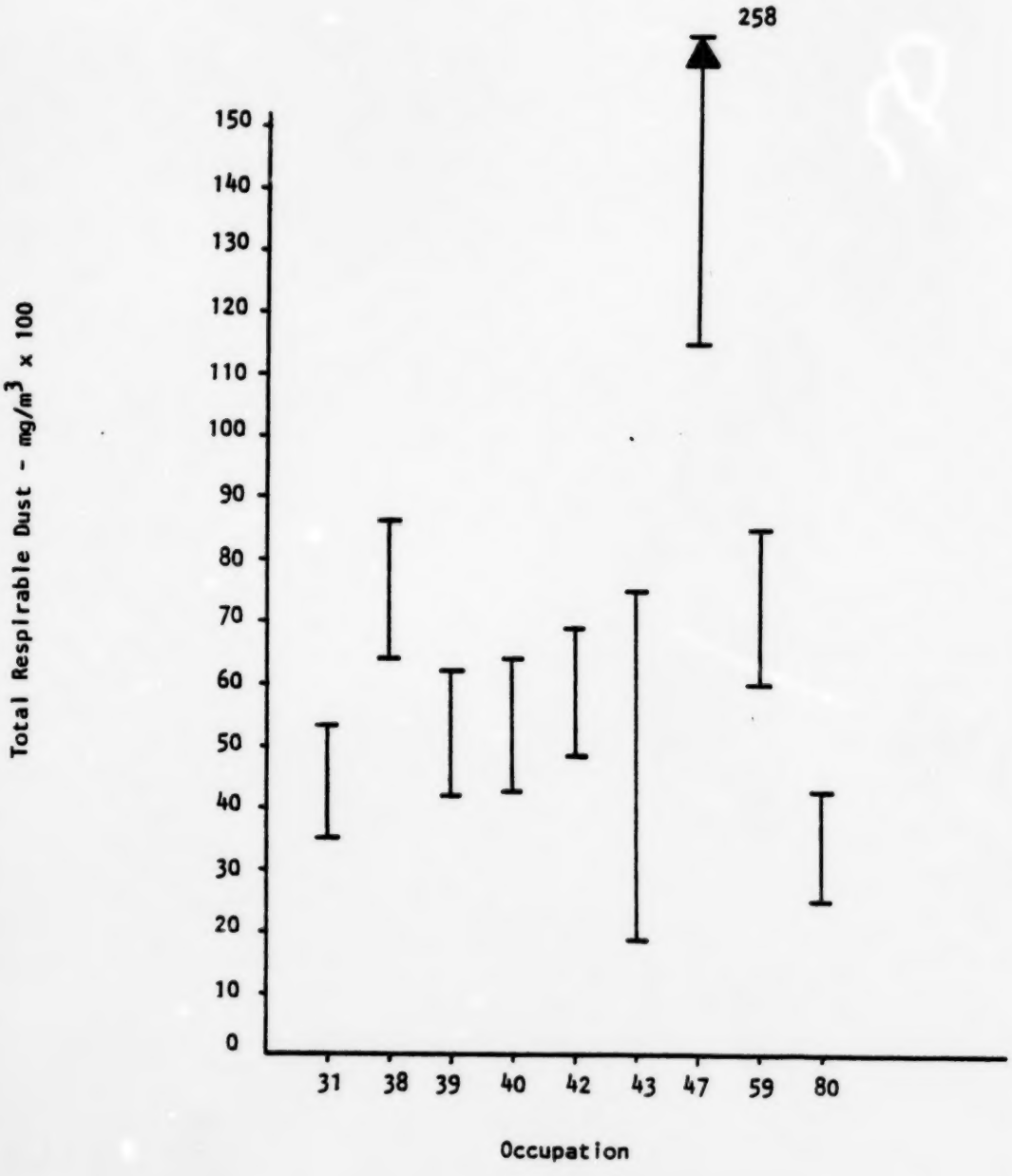
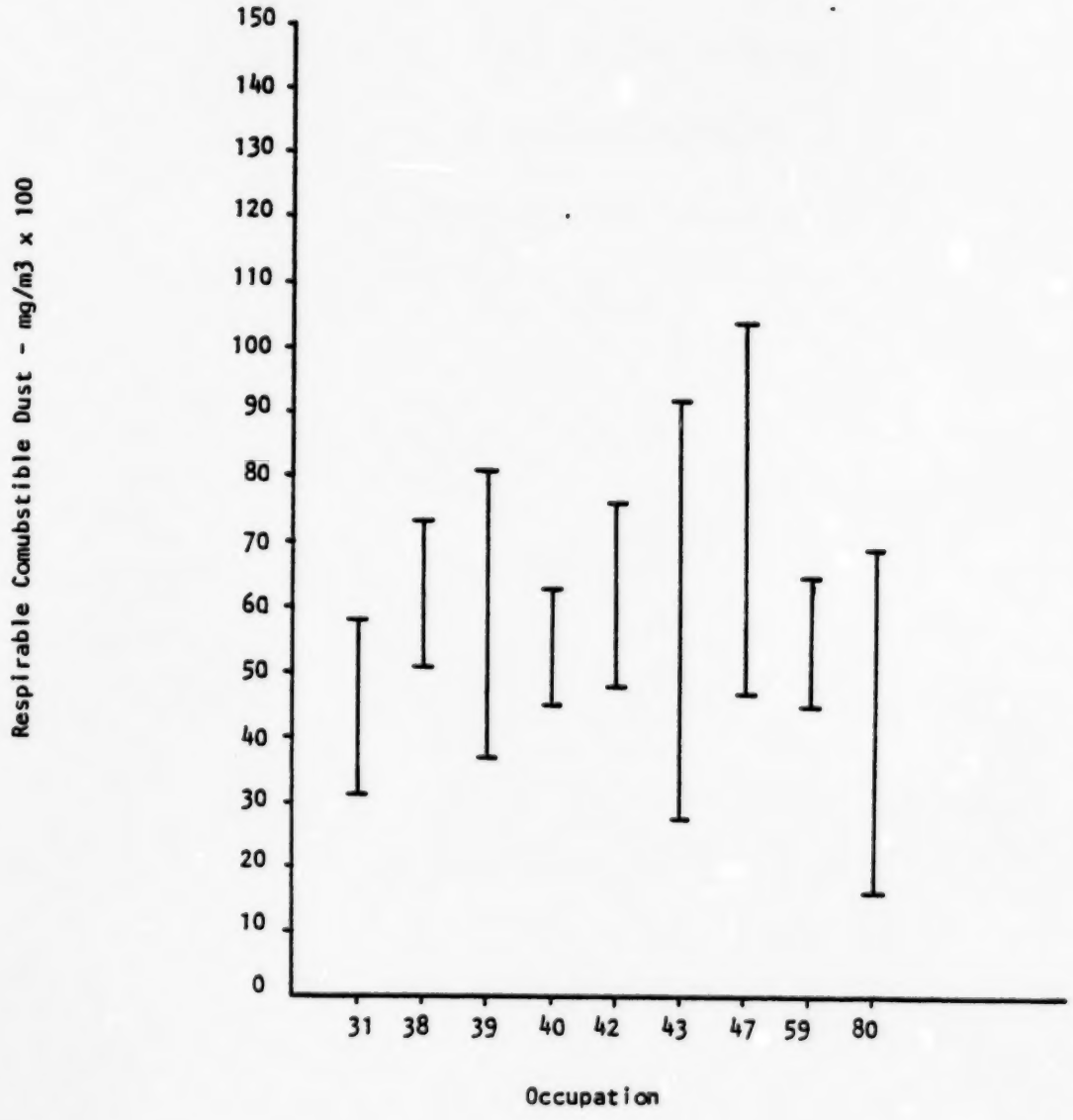


Figure D - 3

Personal Dust Sampling Observations in Uramium Mines

(Respirable Combustible Dust - mg/m3 x 100)



Appendix - E

Assessment of the Assumption of Normality of Individual Observations of Respirable Quartz and Respirable Dust Observations

Appendix - E

Assessment of the Assumption of Normality of Individual Observations of Konimeter Respirable Quartz and Respirable Dust Observations [1] [2]

One of the most frequent assumptions made when applying statistical techniques to the analysis of dust sampling data is that respirable dust, respirable quartz and konimeter observations were drawn from a population which can be described by a normal or log-normal distribution.

The Shapiro and Wilk [3] [4] [5] W test for sample sizes N less than (6) or equal to 50 and the D'Agostino D'Test for sample sizes greater than 50 have been entered into a computer program developed at the Department of Energy Mines and Resources, Ottawa, Canada to analyse the data presented in this Appendix.

The results of these studies of fifteen mines locations and seventeen occupations revealed these observations of respirable quartz data obtained in an Ontario uramium mines to be log-normally distributed (Tables E-1 to E-8).

Konimeter observations obtained in the same mine were also found to be log-normal as shown in Figures E-2 and E-4 and in Tables E-10 and E-12.

Table E-1

Summary of the results of normality/log normality tests of quartz data of Mine B. Data are classified by Areas and Jobs Numbers.

Classifcation	No.	No. of samples	Log-Normal α=0.05	Log-Normal α=0.01	Normal α = 0.05	Normal α = 0.01
Area	1	22	R	A	R	R
	2	20	A	A	R	R
	200	109	A	A	R	R
	400	56	A	A	R	R
	500	37	A	A	R	R
	600	60	A	A	R	A
	700	95	R	R	R	R
	800	114	R	R	R	R
	900	132	A	A	R	R
	1000	63	A	A	R	R
	1100	32	A	A	R	R
	5000	20	A	A	R	A
	6200	24	A	A	A	A
	7000	28	A	A	R	R
	8200	13	A	A	A	A
Job	202	11	A	A	R	R
	204	37	A	A	R	R
	205	36	A	A	R	R
	210	22	A	A	R	R
	300	14	A	A	R	R
	302	14	A	A	A	A
	303	94	R	R	R	R
	304	22	R	R	A	A
	311	33	A	A	R	R
	313	30	R	A	R	A
	315	18	A	A	R	R
	316	15	A	A	A	A
	421	42	A	A	R	R
	501	106	A	A	R	R
	503	216	A	A	R	R
	505	21	A	A	R	R
	506	47	A	A	R	R
All Data		873	R	R	R	R

A - Accepted

R - Rejected

Table E-2

CAMPEDS SAMPLING PROGRAM MINE - B

QUARTZ DATA - LOG TRANSFORMATION

MEAN	1.907856
VARIANCE	.109315
STANDARD DEVIATION	.330629
COEFFICIENT OF VARIATION	17.329848
SKEWNESS FACTOR	.062330
KURTOSIS	4.159360
NO OF SAMPLES	873

D'AGOSTINO D' TEST FOR NORMALITY

NO. OF DATA POINTS	873
CALCULATED D' STATISTIC	7131.17
PROBABILITY LEVEL	.05
CRITICAL REGION - LOW	7221.58
- HIGH	7324.34

NORMALITY HYPOTHESIS IS REJECTED

Table E-3

CAMPEDS SAMPLING PROGRAM MINE - B

LOG OF QUARTZ DATA CLASSIFIED BY AREA NO. 1

MEAN	1.908304
VARIANCE	.148456
STANDARD DEVIATION	.385300
COEFFICIENT OF VARIATION	20.190692
SKEWNESS FACTOR	1.425065
KURTOSIS	5.932506
NO OF SAMPLES	22

SHAPIRO-WILK W TEST FOR NORMALITY

NO. OF DATA POINTS	22
CALCULATED W-STATISTIC	.8836
PROBABILITY LEVEL	.05
CRITICAL VALUE	.9110

NORMALITY HYPOTHESIS IS REJECTED

CALCULATED Z VALUE	-2.2216
PROBABILITY OF Z LESS THAN THIS	.131541E-01

Table E-4

CAMPEDS SAMPLING PROGRAM MINE - B

LOG OF QUARTZ DATA CLASSIFIED BY AREA NO. 2

MEAN	1.829059
VARIANCE	.056545
STANDARD DEVIATION	.237791
COEFFICIENT OF VARIATION	13.000752
SKEWNESS FACTOR	.655113
KURTOSIS	3.713205
NO OF SAMPLES	20

SHAPIRO-WILK W TEST FOR NORMALITY

NO. OF DATA POINTS	20
CALCULATED W-STATISTIC	.9511
PROBABILITY LEVEL	.05
CRITICAL VALUE	.9050

NORMALITY HYPOTHESIS IS ACCEPTED

Table E-5

CAMPEDS SAMPLING PROGRAM MINE-B

LOG OF QUARTZ DATA CLASSIFIED BY AREA NO. 200

MEAN	1.964232
VARIANCE	.065255
STANDARD DEVIATION	.255450
COEFFICIENT OF VARIATION	13.005096
SKEWNESS FACTOR	.376533
KURTOSIS	3.211280
NO OF SAMPLES	109

D'AGOSTINO D'TEST FOR NORMALITY

NO. OF DATA POINTS	109
CALCULATED D'-STATISTIC	318.73
PROBABILITY LEVEL	.05
CRITICAL REGION - LOW	313.73
- HIGH	326.37

NORMALITY HYPOTHESIS IS ACCEPTED

Table E-6

CAMPEDS SAMPLING PROGRAM MINE -B

LOG OF QUARTZ DATA CLASSIFIED BY AREA NO. 400

MEAN	1.945800
VARIANCE	.072617
STANDARD DEVIATION	.269476
COEFFICIENT OF VARIATION	13.849099
SKEWNESS FACTOR	.522255
KURTOSIS	3.657340
NO OF SAMPLES	56

D'AGOSTINO D' TEST FOR NORMALITY

NO. OF DATA POINTS	56
CALCULATED D'-STATISTIC	115.25
PROBABILITY LEVEL	.05
CRITICAL REGION - LOW	113.60
- HIGH	120.00

NORMALITY HYPOTHESIS IS ACCEPTED

Table E-7

CAMPEDS SAMPLING PROGRAM MINE-B

LOG OF QUARTZ DATA CLASSIFIED BY AREA NO. 500

MEAN	1.897781
VARIANCE	.111592
STANDARD DEVIATION	.334053
COEFFICIENT OF VARIATION	17.602311
SKEWNESS FACTOR	.094949
KURTOSIS	3.148930
NO OF SAMPLES	37

SHAPIRO-WILK W TEST FOR NORMALITY

NO. OF DATA POINTS	37
CALCULATED W-STATISTIC	.9902
PROBABILITY LEVEL	.05
CRITICAL VALUE	.9360

NORMALITY HYPOTHESIS IS ACCEPTED

Table E-8

CAMPEDS SAMPLING PROGRAM MINE-B

LOG OF QUARTZ DATA CLASSIFIED BY AREA NO. 600

MEAN	1.894081
VARIANCE	.080744
STANDARD DEVIATION	.284155
COEFFICIENT OF VARIATION	15.002292
SKEWNESS FACTOR	-.021804
KURTOSIS	2.182585
NO OF SAMPLES	60

D'AGOSTINO D'TEST FOR NORMALITY

NO. OF DATA POINTS	60
CALCULATED D'-STATISTIC	133.07
PROBABILITY LEVEL	.05
CRITICAL REGION - LOW	126.30
- HIGH	133.10

NORMALITY HYPOTHESIS IS ACCEPTED

Figure E-1

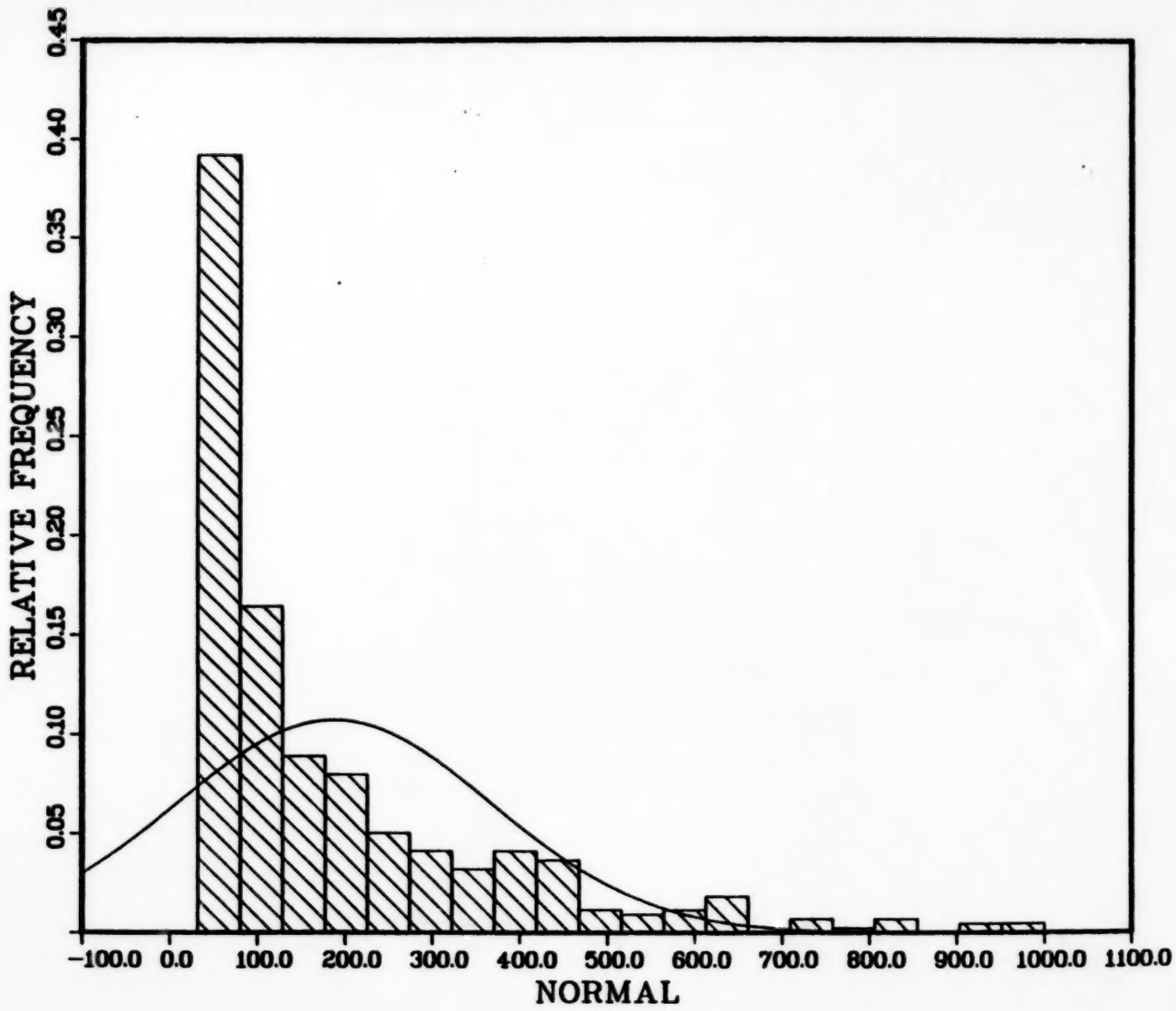

SERIES-1 KONIMETER DATA PPCC
RELATIVE FREQUENCY
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
-100.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
NORMAL

Table E-9

SERIES - 1 KONIMETER DATA PPCC

NORMAL

MEAN	187.492027
VARIANCE	32547.428589
STANDARD DEVIATION	180.409059
COEFFICIENT OF VARIATION	96.222256
SKEWNESS FACTOR	1.857579
KURTOSIS	6.611432
NO OF SAMPLES	439

D'AGOSTINO D' TEST FOR NORMALITY

NO. OF DATA POINTS	439
CALCULATED D'-STATISTIC	2244.06
PROBABILITY LEVEL	.05
CRITICAL REGION - LOW	2565,30
- HIGH	2616.20

NORMALITY HYPOTHESIS IS REJECTED

Figure E-2

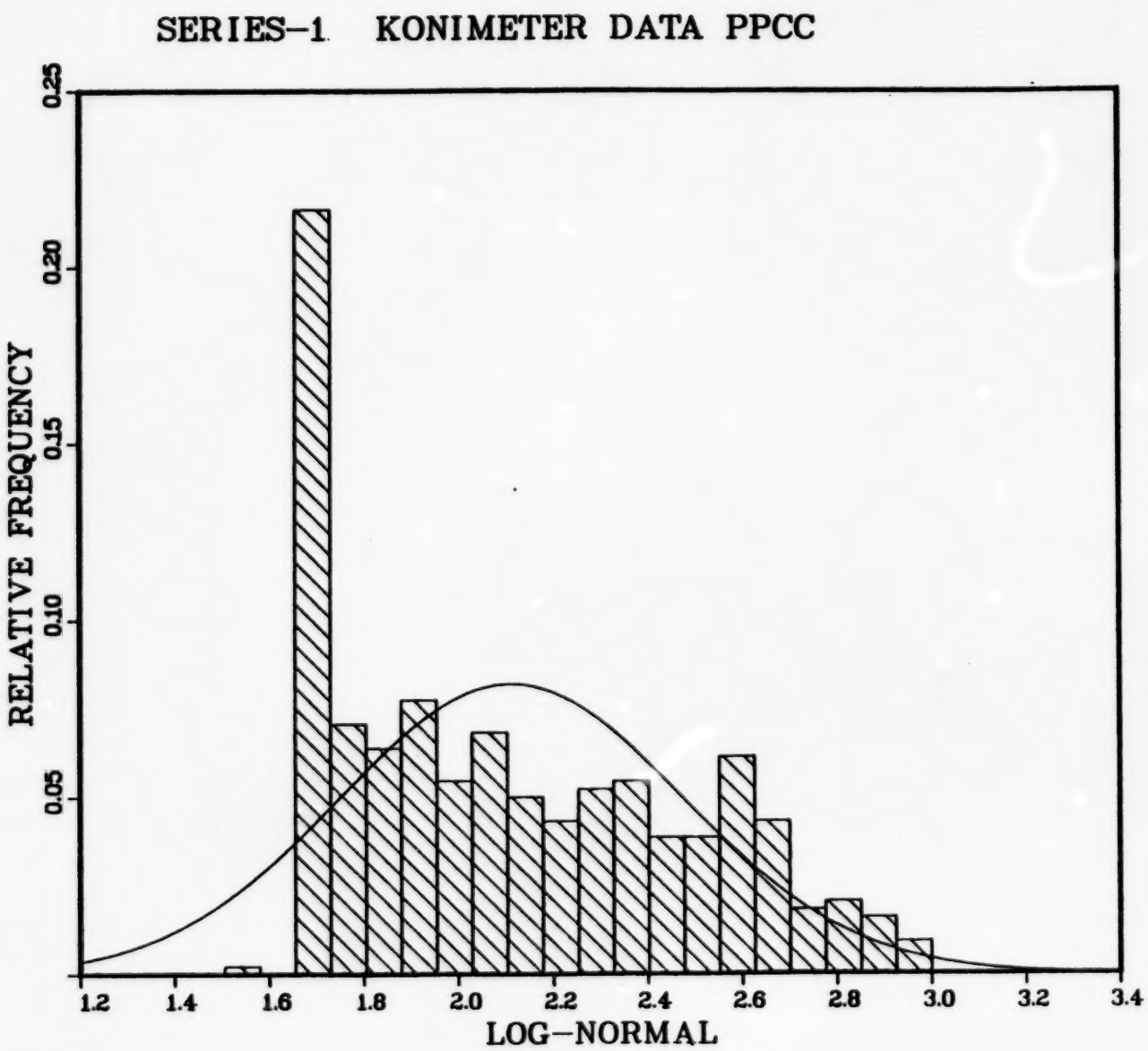

SERIES-1 KONIMETER DATA PPCC
RELATIVE FREQUENCY
0.25
0.20
0.15
0.10
0.05
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
LOG-NORMAL

Table E-10

SERIES - 1 KONIMETER DATA PPCC

LOG-NORMAL TEST

MEAN	2.111192
VARIANCE	.132137
STANDARD DEVIATION	.363507
COEFFICIENT OF VARIATION	17.218088
SKEWNESS FACTOR	.491077
KURTOSIS	2.059192
NO OF SAMPLES	439

D'AGOSTINO D' TEST FOR NORMALITY

NO. OF DATA POINTS	439
CALCULATED D'-STATISTIC	2598.38
PROBABILITY LEVEL	.05
CRITICAL REGION - LOW	2565.30
- HIGH	2616.20

NORMALITY HYPOTHESIS IS ACCEPTED

Figure E-3

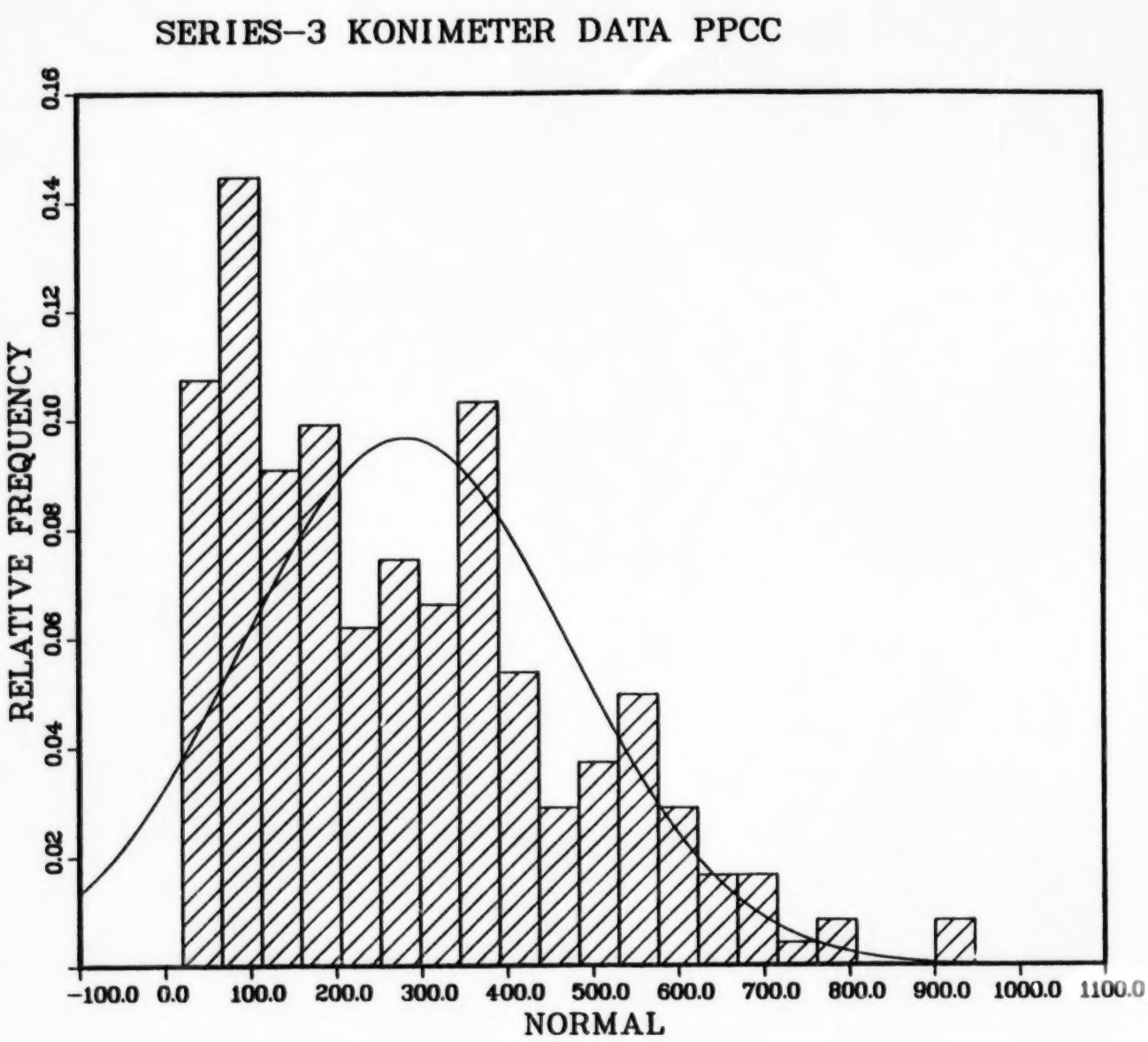

SERIES-3 KONIMETER DATA PPCC
RELATIVE FREQUENCY
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
-100.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
NORMAL

Table E-11

SERIES - 3 KONIMETER DATA PPCC

NORMAL

MEAN	281.793388
VARIANCE	36544.006927
STANDARD DEVIATION	191.164868
COEFFICIENT OF VARIATION	67.838663
SKEWNESS FACTOR	.825004
KURTOSIS	3.229404
NO OF SAMPLES	242

D'AGOSTINO D' TEST FOR NORMALITY

NO. OF DATA POINTS	242
CALCULATED D'-STATISTIC	1044.38
PROBABILITY LEVEL	.05
CRITICAL REGION - LOW	1045.20
- HIGH	1073.50

NORMALITY HYPOTHESIS IS REJECTED

Figure E-4

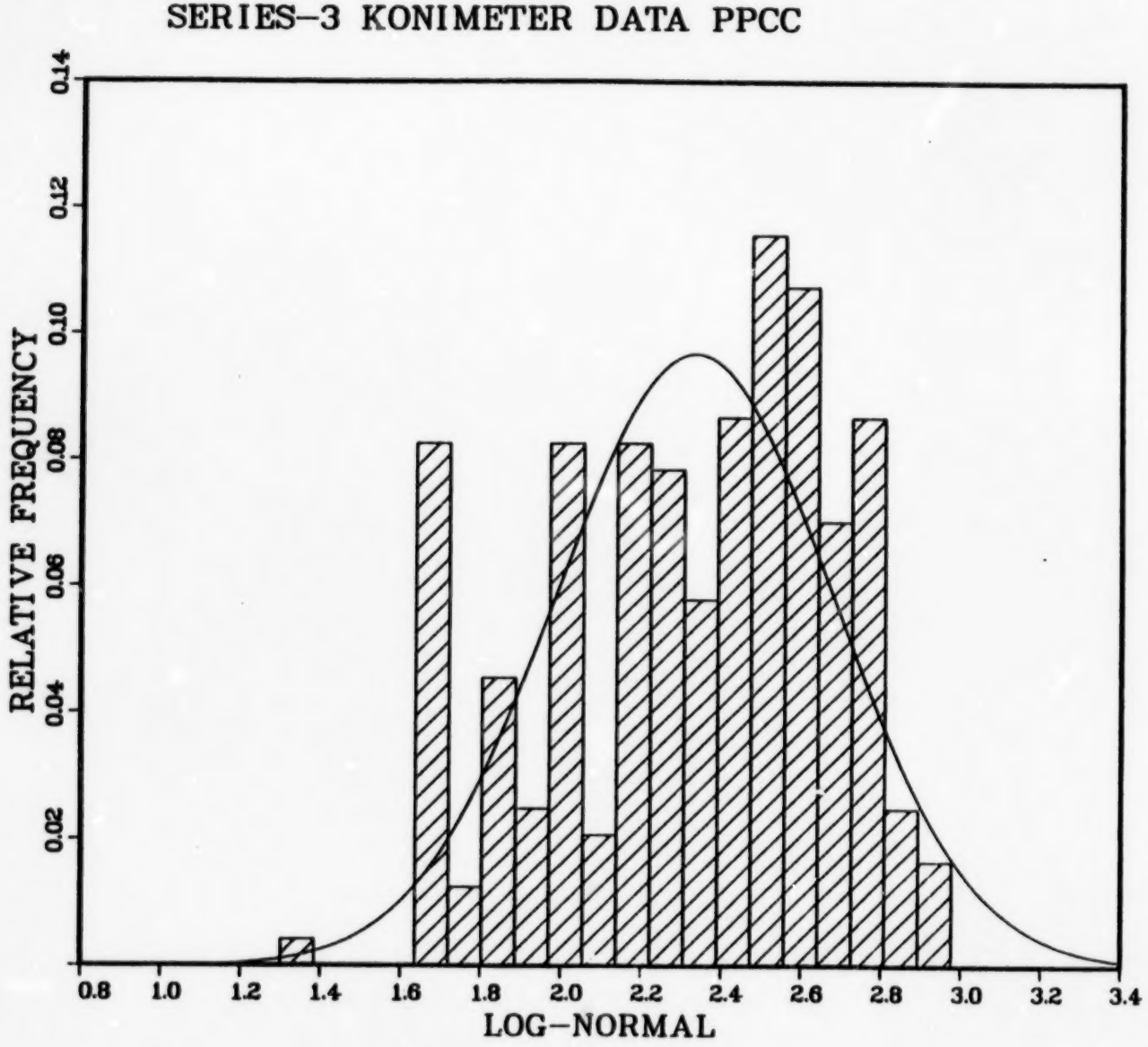

SERIES–3 KONIMETER DATA PPCC
RELATIVE FREQUENCY
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
LOG–NORMAL

Table E-12

SERIES - 3 KONIMETER DATA PPCC

LOG-NORMAL TEST

MEAN	2.332145
VARIANCE	.119049
STANDARD DEVIATION	.345034
COEFFICIENT OF VARIATION	14.704718
SKEWNESS FACTOR	-.442779
KURTOSIS	2.305811
NO OF SAMPLES	242

D'AGOSTINO D' TEST FOR NORMALITY

NO. OF DATA POINTS	242
CALCULATED D'-STATISTIC	1068.68
PROBABILITY LEVEL	.05
CRITICAL REGION - LOW	1045.20
- HIGH	1073.50

NORMALITY HYPOTHESIS IS ACCEPTED

Table E-13

Dust Sampling Konimeter

Ln (Particles Per Cubic Centimeter)

ln (p.p.c.c.)

Calculation Using Lognormal Theory,

of m, a Statistic to Estimate the

Mean u and V^2 a Statistic to Estimate

S_u^2 . Series 1 Data

Calculation of m		Calculation of V^2	
Notation	Value	Notation	Value
$\bar{u}$	4.8611992	$\bar{u}$	4.8611992
S_u^2	0.3042566	S_u^2	0.3042566
$e^{\bar{u}}$	129.02	$2\bar{u}$	9.623984
N	438	e^{2u}	15063
$T = \frac{1}{2} S_u^2$	0.1521283	N	438
$\psi(\frac{1}{2} S_u^2)$	1.161	ϕ_n (Su)	0.470
m =		V^2	
$(e^{\bar{u}})$ $\psi_n(\frac{1}{2}$ Su)	129.02x1.161	$= e^{u}$ (ϕn (S_u^2)	15063 x 47
m =	149.79 p.p.c.c.	V^2 =	7079.61
		V =	84.14 p.p.c.c.

Table E-14

Dust Sampling Konimeter

Ln (Particles Per Cubic Centimeter)

Ln (p.p.c.c.)

Calculation Using Lognormal Theory,

of m, a Statistic to Estimate the

Mean u and V^2 a Statistic to Estimate

S_u^2 . Series 3 Data

Calculation of m		Calculation of V^2	
Notation	Value	Notation	Value
$\bar{u}$	5.369962	$\bar{u}$	5.369962
S_u^2	0.2741205	S_u^2	0.2741205
$e^{\bar{u}}$	212.72	$2\bar{u}$	10.739924
N	242	e^{2u}	22026
$T = \frac{1}{2} S_u^2$	0.137060	N	242
$\psi n\ (\frac{1}{2} S_u^2)$	1.138	$\phi_n\ (S_u^2)$	0.403
m =		V^2 =	22026 x 0.403
$(e^{\bar{u}})\ \psi n\ (\frac{1}{2} S_u^2)$	212.72 x 1.138	V^2 =	8876.48
		V =	94.22 p.p.c.c.
m =	242.075		
	242.1 p/p.c.c.		

Appendix - F

Use of Log-normal Theory to Calculate the Best Estimate of the Mean and Standard Deviation of Konimeter, Respirable Dust and Respirable Quartz Observations.

Appendix - F

Use of Log-normal Theory to Calculate the Best Estimate of the Mean and Standard Deviation of Konimeter Respirable Dust and Respirable Quartz Observations.

Although log-normal theory and the log-normal distribution had been known for more than fifty years applied to biological data and the size distributions of dust and powders it has since been a most useful technique in the applied statistical analysis of rare metal concentrations in ore samples. Statistical tables Aitchison and Brown[20] and the U.S. Bureau of Mines RI - 7495[19] have also been applied to the statistical analysis of radon daughter observations in the homes and buildings in municiplaities in Ontario and Saskatchewan.

The Normal Distribution.

The normal probability distribution is functionally presented as:-

$$P(y) = \frac{1}{\sigma\sqrt{2n}} \exp \frac{(x-\overline{x})^2}{2\sigma^2} \text{ --------- (1)}$$

where $\overline{X}$ is the mean of a symetric distrubtion and σ the standard deviation.

Graphically

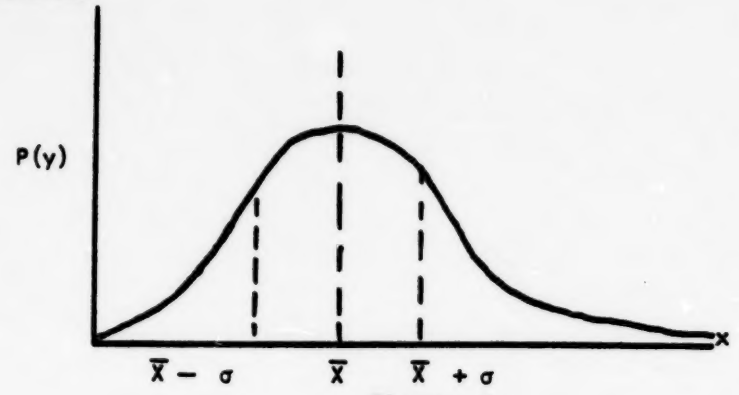


Figure 1

In this distribution if a distance equal to σ is measured off on the X axis on both aides of $\overline{X}$ the arithmetic mean in a normal distribution 68.26% of the values will be included within the limits indicated. If two standard deviations are measured off 95.46% of the items will be included. Three standard deviations measured off will include 99.73% of the observations.

The Log-Normal Distribution

It is evident from the results of studies of respirable dust, respirable quartz and konimeter data presented in the Appendices that when a logarithmic transformation of the individual observations is followed by a statistical analysis the data are found to be robust.

This conclusive evidence that the dust sampling data are log-normally distributed is presented in Appendices A, B and C.

The log-normal distribution may be represented as follows:-

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} \frac{1}{x} \exp \frac{(\ln x - u)^2}{2\sigma^2} \quad \text{-------- (2)}$$

where,

ln x refers to the natural logarithm of x_i. Should logarithms to the base 10 be used the subsequent statistical analysis is completed by the introduction of an additional normalizing factor.

As indicated graphically the log-normal distribution is skewed to the right as shown:-

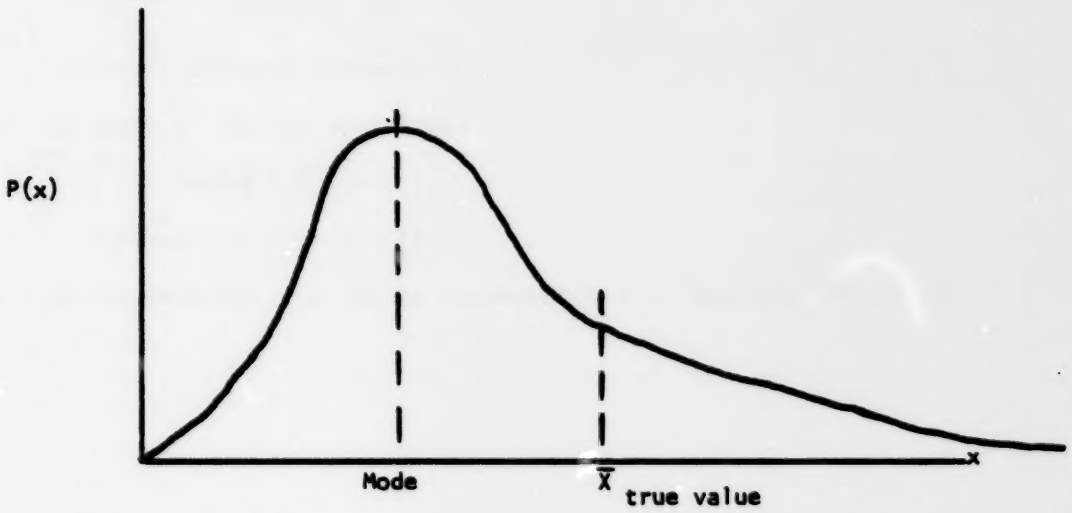


Figure - 2

This skewed distribution where $x \geqslant \sigma$ reaches a mode before the true arithmetic mean tails off to infinity.

Since a simple arithmetic average cannot be used to calculate the true mean of a skewed distribution as is the case in the conventional normal curve, there is a tendency for this average to underestimate the true mean of the log-normal distribution.

However, should one use the logarithmic transformation for individual observations the conventional normal distribution $y_i = \ln x_i$ for all of the individual observations the skewed distribution is transformed into that presented in equation 1 figure 1. Although this method facilitates the calculation of $\overline{X}_{\log}$ and $\sigma_{\log}$ the best estimate of $\overline{x}$ and σ in mg/M^3 or p.p.c.c. requires additional analytical procedures.

Calculation of the Best Estimate of the Mean u and the Standard Deviation Su.

The best estimate of the mean can then be found conforming to an expression from Aitchison and Brown (20).

$$m = e^{\overline{u}} \; \psi n \; (\tfrac{1}{2} \; Su^2) \text{ -------- (3)}$$

where, $\psi n = 1 + \frac{n-1}{n} \; V + \frac{(n-1)^2}{n^2(n-1)} \; \frac{V^2}{2!}$

m is the unbiased efficent estimate of u.

and the best estimate of the variance from,

$$V = e^{2\overline{u}} \left(\psi(2 \; Su^2 - \psi \; n \; (\tfrac{n-2}{n-1} \; Su^2) \right)$$

$$= e^{2\overline{u}} \; (\; \phi(Su^2)) \text{ ---------- (4)}$$

ψ and V may be obtained from tables presented in U.S. Bureau of Mines (19).

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